APRIL 1954

Journal
of
The Franklin Institute

1826

1954

Science and the Peace Officer

JOHN EDGAR HOOVER

The Synthesis of Sequential Switching Circuits

D. A. HUFFMAN

The Coulomb Force and the Ampère Force

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Entered as second-class matter March 14, 1928, at the post office at Lancaster, Pa., under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in paragraph (d-2), section 34.40, P. L. & R. of 1948, authorized on July 3, 1919.

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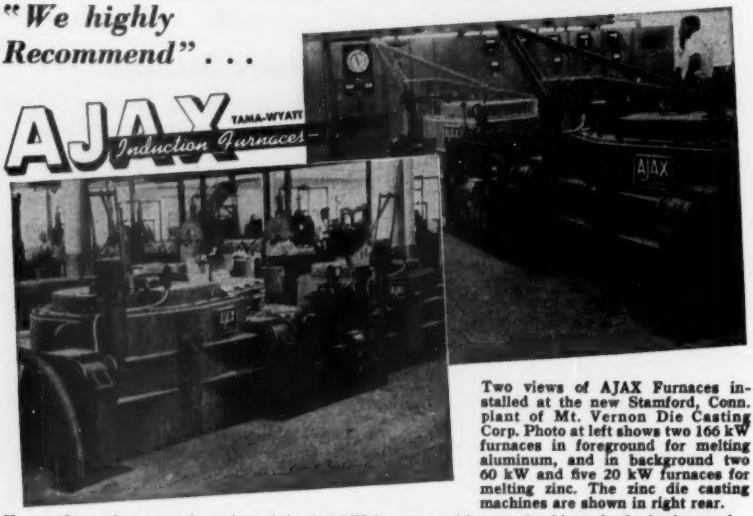

Two views of AJAX Furnaces installed at the new Stamford, Conn. plant of Mt. Vernon Die Casting Corp. Photo at left shows two 166 kW furnaces in foreground for melting aluminum, and in background two 60 kW and five 20 kW furnaces for melting zinc. The zinc die casting machines are shown in right rear.

Upper photo shows another view of the 166 kW furnaces, with control cabinets in the background.

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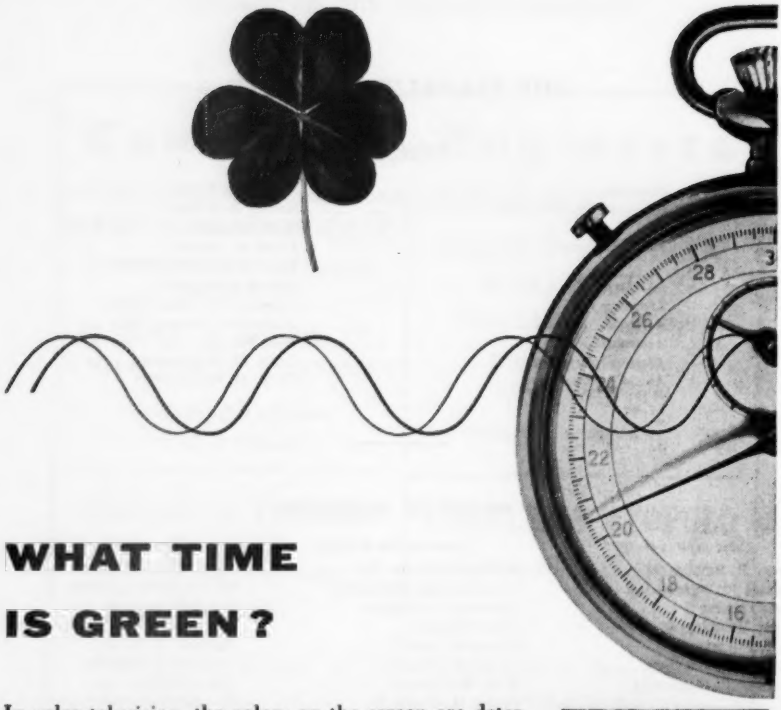

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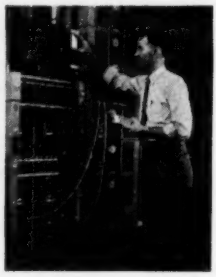
This important contribution to color television is another example of the pioneer work done by Bell Telephone Laboratories to give America the finest communications in the world.



To keep colors true in television, signals must be kept on one of the world's strictest timetables. Equalizers that correct off-schedule waves are put into place at main repeater stations of the transcontinental radio-relay system.

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Published monthly by The Franklin Institute of the State of Pennsylvania, Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Pennsylvania. Printed by Lancaster Press, Inc., Prince and Lemon Sts., Lancaster, Pennsylvania.

Subscription rates: Domestic, $10.00 a year; Foreign, $11.00 a year. Single current issues, $1.00. Reprints, 50 cents per installment. All inquiries regarding subscriptions, change of address, sale of back issues and reprints, should be addressed to the Philadelphia office.

Indexes to the semi-annual volumes of the JOURNAL are published in the June and December numbers.

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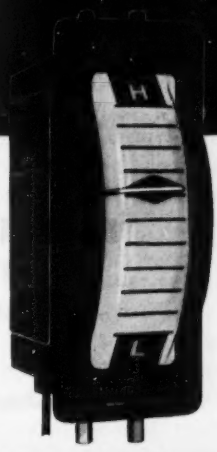

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Vol. 257 APRIL, 1954 No. 4

SCIENCE AND THE PEACE OFFICER

BY

JOHN EDGAR HOOVER[1]

Highly technical developments from the realm of science have, in recent years, been adapted so successfully to the needs of law enforcement that they are daily proving to be a sharp sword in behalf of justice. In case after case, the scales of justice have been held in balance—both in fixing guilt and in proving innocence—through subjecting evidence to examination involving technical equipment such as microscopes, spectrographs, X-ray units, diffraction units and spectrophotometers.

But no laboratory, regardless of how well-staffed and well-equipped, could give maximum service to law enforcement were the individual officer unaware of the vast number of ways in which highly technical instruments are continuously being adapted to purposes of crime detection.

The FBI Laboratory was established in 1932. Its purpose was to increase the vision of the investigator; therefore, a microscope, forerunner of the widely varied modern precision instruments which find truth in a fleck of paint or a wisp of thread, became the first piece of equipment.

All services of the FBI Laboratory, including the court testimony of its examiners, are available without cost to other Federal Government agencies, and also to local law enforcement agencies throughout the country. This fact has put every scientific advance applicable to law enforcement within reach of the smallest and most remote agency. Today, evidence recovered by a sheriff in a rural area may receive the same objective chemical, physical and microscopic examination which, until recently, was available only to a limited number of urban law-enforcement agencies.

[1] Director, Federal Bureau of Investigation, United States Department of Justice, Washington, D. C.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

Do law-enforcement agencies utilize this cost-free service? During the 1953 fiscal year, the FBI Laboratory conducted 121,064 examinations of evidence, an increase of 10.3 per cent over the 109,733 examinations which were made the previous year. These examinations were made in connection with 25,262 individual requests and involved 111,320 specimens of evidence. The requests for examination of these specimens came from all 48 states, the District of Columbia, Alaska, Hawaii, Puerto Rico, the Virgin Islands, and officials of Korea and Canada. Of the 121,064 examinations conducted in the FBI Laboratory during the 1953 fiscal year, 73,276 were conducted in the Document Section.

FIG. 1. A portion of the Document Section, FBI Laboratory, Washington, D. C.

The lay person, thinking in terms of documents, usually visualizes typed or handwritten pieces of paper. Document examinations, therefore, are too often believed to be merely studies of simple messages written on paper. Actually, the average document examination encompasses far more than the study of paper or the study of the writing itself. The possibilities of obliterations, indented writing, and torn edges must not be overlooked. Again and again, these types of examinations have helped to reveal the truth. In a recent instance, a study of obliterated writing helped to expose a fraudulent alibi and bring the guilty individuals to justice. This case concerned a major bank robbery in a Midwestern city.

Two men crowded a bank official's car to the curb and made off with approximately $71,000 in currency. Following investigation, two suspects were indicted and brought to trial. At the trial, one of the suspects maintained that while the robbery was taking place in one city, he was receiving medical treatment in the office of a doctor in another city. The doctor in question testified regarding the pertinent date and produced in evidence a card for the patient indicating that the suspect actually had been in the doctor's office on August 14, the date of the robbery. The 4 in the August 14 date on the card, however, had been written in ink over a stamped date and the FBI Laboratory was requested to conduct an examination of the document which was so vital a piece of evidence.

When received in the FBI Laboratory, the document was subjected to various scientific examinations. It was photographed first under ultraviolet and secondly under infrared exposures.

Certain inks are transparent under infrared rays while others are opaque. As the FBI Laboratory technician examined the document under infrared rays he found that part of a stamped figure, either a 6 or an 8 and probably an 8, had been placed initially under the questioned figure 4 in the date of August 14. He found also that the ink used to write all notations regarding the patient, with the exception of the handwritten 4, was transparent to infrared light. In addition, a microscopic examination revealed that a handwritten figure, either a 6 or an 8, and probably the latter, in the same type ink as all other notations with the exception of the 4, had been written over the original stamped figure and appeared under the handwritten 4. Further, the examination under infrared light disclosed definitely that the composition of the ink in which the 4 was written differed completely from the ink in which all other handwritten notations were written. It was not transparent to infrared rays.

Summed up briefly, the examiner found that the date originally stamped on the card was either August 16 or 18. Since the date stamp had not registered clearly, someone had apparently written over the date stamp in ink the pertinent date—either August 16 or 18. A third figure—a plain, heavily inked 4—had been superimposed on both prior figures, so that to the eye, the date on the patient card read August 14.

The doctor had testified that he had written the 4 in August 14 on his treatment card when his rubber date stamp had failed to work properly. He stated, under cross-examination, that the suspect had first come to him for treatment on August 12. He had told the patient to return for another treatment on August 18, but, according to his testimony, the man had actually returned to his office on August 14. Since August 14 was the day of the robbery, proof that he had been in the doctor's office at the pertinent time would give the suspect a good alibi.

The FBI Laboratory examiner was called as a rebuttal witness for the Government. With use of photographic enlargements which included a 22-time enlargement of an infrared photograph, he testified as to his findings.

The suspect, his alibi thus nullified through utilization of scientific methods to secure the truth, was found guilty and eventually sentenced

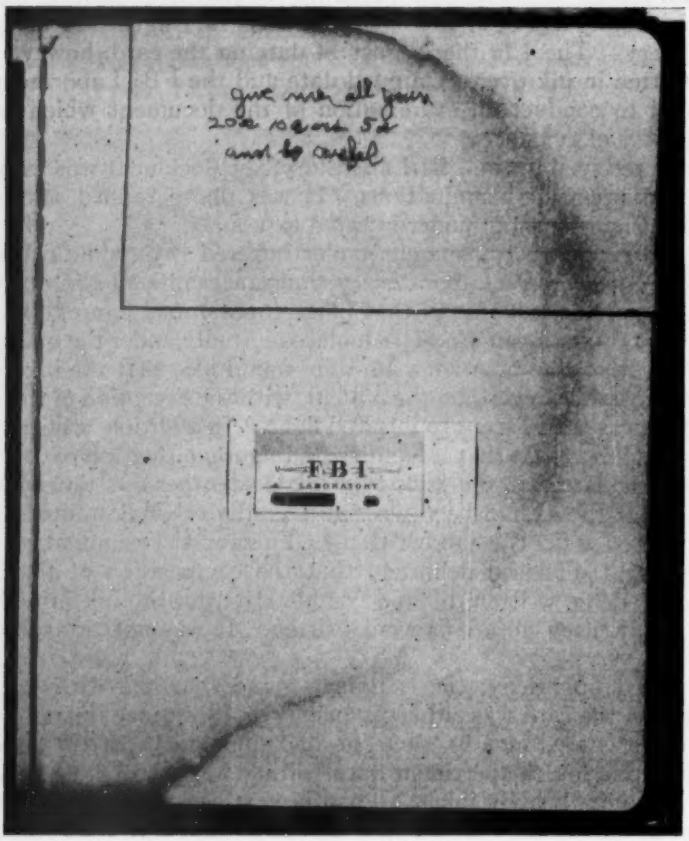

FIG. 2. Handwritten note left by robber in victim bank is shown as it fitted into cut space in notebook found in suspect's room. Note matching water stain.

to serve fifteen years in prison. The doctor in question was later charged with perjury and brought to trial. In the course of his trial, the FBI Laboratory technician was again called to testify as to the facts of his various examinations. The doctor was convicted of committing perjury.

Examinations involving torn edges of documents and indented writing are of particular value in law-enforcement work. In one instance, FBI Laboratory examinations involving the use of parallel light rays

helped to identify the lone bandit responsible for a brazen bank robbery in a West Coast city. Disguised with make-up and false mustache, the thief pushed a crudely written note across the counter at a teller's window. The note read, "Give me all your 20's, 10's and 5's and be careful." A .38-caliber automatic pistol gave emphasis to the demand and the bank bandit secured a small sum of money and made good his escape. Considerable evidence was developed which pointed suspicion to a man whose record showed a prior conviction for the crime of bank robbery. Placed under arrest, the ex-convict denied being implicated in the rob-

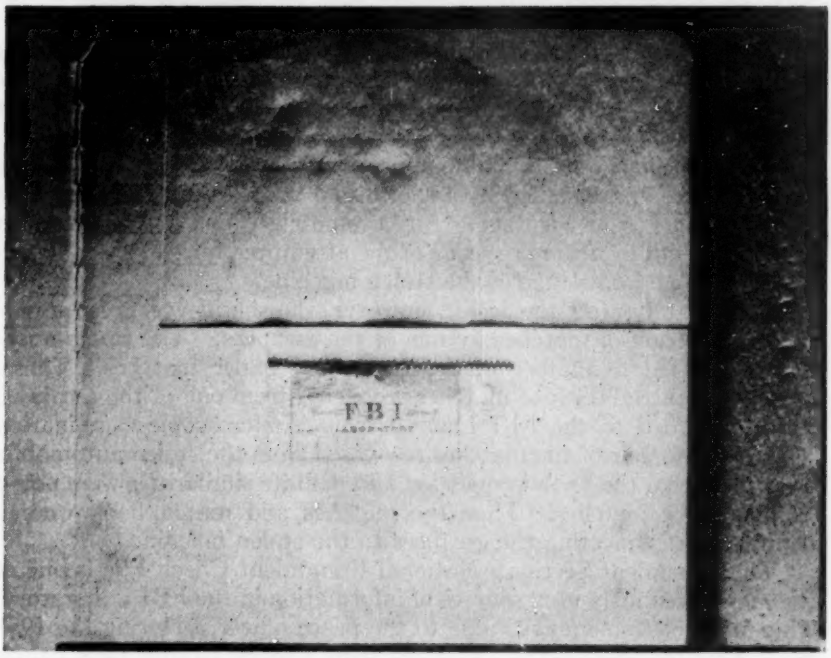

FIG. 3. Indented writing in notebook located in bank robbery suspect's room as photographed under parallel light rays.

bery. A search of his bedroom, however, revealed a notebook from which a section of one page was missing. The demand note left by the bandit at the time of the robbery was placed in the missing section of the notebook and was found to fit perfectly. On the opposite page was written "Give me all your 5's, 10's. . . ."

This was only a small part of the evidence uncovered by investigators. Samples of the suspect's handwriting were obtained and these, together with the notebook found at his home and the demand note left by the robber at the victim bank, were forwarded to the FBI Laboratory. By projecting a parallel beam of light across the page beneath

the one from which the note appeared to have been cut, the examining technician found that written impressions showed forth clearly. A photograph was made and it was found that the impression of writing on the notebook was identical in every detail with the note which the bandit gave the bank teller. In addition, technicians concluded from their examination that the demand note left at the victim bank and the known samples of the suspect's handwriting had been written by the same person.

The suspect entered a plea of not guilty to charges against him, but when he was brought to trial, he changed his plea to guilty and was sentenced to five years' imprisonment.

Another variation of a study of torn edges, illustrating the manner in which this type of document examination can be adapted to crime detection work, involved a simple item—a book of matches. Yet it helped link suspects to a crime.

Five prisoners broke jail in a central state. Later, two of the escapees were apprehended by a sheriff in a western state as they were attempting to enter a garage. An automobile which had been stolen was parked not far from the scene of the attempted burglary. The two men denied all knowledge of the stolen machine.

Immediately after the arrest, however, the sheriff was given a partially used book of matches by one of the escapees. The stolen automobile yielded a number of partly burned paper matches. These, together with the book of matches recovered from one of the escapees, were forwarded to the FBI Laboratory. A microscopic examination revealed that four of the matches recovered from the stolen automobile were torn from the book in question and definite similarities were noted in two other matches. Thus the matches and match book were a definite link connecting the escapees to the stolen machine.

The Document Section's National Fraudulent Check File is one of the most constantly used sources of information in the FBI Laboratory. This file is of tremendous value to the peace officer. During the 1953 fiscal year, a total of 19,436 fraudulent checks having face values amounting to $3,211,098 were received for examination. This was an increase of 2,839 over the previous 12-month period. A total of 20,630 searches were conducted in the National Fraudulent Check File during the fiscal year 1953.

The National Fraudulent Check File is especially valuable in identifying the professional check passer who moves constantly and who changes his name every time he moves.

One such individual, an ex-convict whose record included the crimes of burglary and auto theft, learned the printing trade in the course of a sojourn in the penitentiary. On his release from prison he secured employment in a printing shop, but he didn't stay long. He used the print shop equipment at night to make up fraudulent checks, money

orders and identification cards, and began passing fraudulent checks, in amounts varying from $20 to $100. In the period of a few months he cashed approximately 100 checks, totaling more than $5,000, in St. Louis, Kansas City, Dallas and Houston.

Police departments in the various cities submitted the checks to the FBI Laboratory. Document examiners, on the basis of make-up from

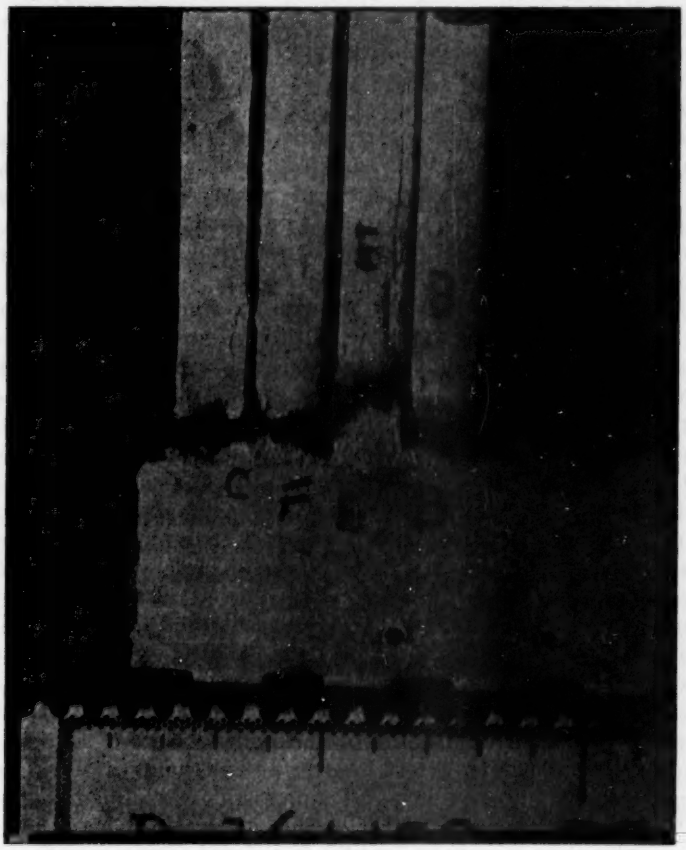

FIG. 4. Burned matches found in stolen automobile are found to have been removed from match book recovered from suspect's person.

elaborate check-protector impressions, fancy rubber stamps, and hand-written signatures, were able to identify the checks as having been prepared by the same individual. They found that two types of check safety paper had been used. They were also able to identify the company which had manufactured the type. The ex-convict painstakingly dubbed a check-protector effect on each check he prepared and he also

used legitimate rubber-stamp signatures. But the very size of his operations led to his apprehension. He forgot his "working alias," absentmindedly endorsed a check in a name other than that of the payee, and was promptly apprehended by an earlier victim who had become suspicious of his activities and followed him.

The FBI Laboratory conducts many examinations separate and distinct from those involving documents. Some of these are conducted in the Chemical Unit and the Spectrographic Unit. Others are handled in units devoted to Serology, Firearms, Metallurgy, Hairs and Fibers, and Petrography.

The FBI Laboratory cannot predict the types of evidence which will be submitted to it, nor can it specify from moment to moment the types of examinations which such evidence will require. It must, therefore, be prepared to conduct a broad variety of examinations. For example, a bullet taken from a shooting victim's body, under microscopic examination in the Firearms Section, may yield invaluable information to the law-enforcement officer.

This is illustrated in the case of a holdup-murder which occurred on March 22, 1952, in Atlanta, Georgia. A lone employee of a liquor store was shot. His killers fled. There were no witnesses. A bullet was recovered from the body of the victim. This bullet, the only clue to the murder, was sent to the FBI Laboratory. Examiners listed the types of guns which could have fired the fatal bullet. With this lone clue to work upon, police officers began a methodical check. Within a month's time, approximately 50 guns of the type listed in the Laboratory report were recovered and test fired. Sample bullets from each weapon were sent to the Laboratory. On the evening of May 2, 1952, a telegram from the Laboratory was received in the Atlanta Police Department. It read: "Original evidence bullet submitted this case identified as fired from caliber point three eight U. S. revolver number one seven eight one naught . . . Report follows."

Police officers hurried to the pawn shop in which they had located the revolver, secured the name of the man who had pawned it, and promptly put him under arrest. After first denying implication in the crime, the suspect broke down and confessed. He named a companion who he alleged did the actual shooting. Both men were brought to trial, convicted and sentenced to life imprisonment.

A single paint chip, forwarded to the FBI Laboratory's Spectrographic or Instrument Analysis Unit by an alert officer in a distant state, may prove to be the key to the crime. Often the examiners are faced with the questions: "Could this fleck of paint have come from a hit-and-run vehicle? If so, can it yield information as to the kind of vehicle involved?"

In one case the Chief of Police of a city in a Midwestern state submitted a chip of paint found at the scene of an accident involving a hit-

and-run driver who had struck a 38-year-old man. The Chief of Police requested that the make and model of the unknown car be determined if possible.

The FBI Laboratory examiner found that the chip consisted of seven layers of paint, indicating that the automobile involved had been repainted three times and was presently a light blue-gray in color. The sixth layer down was believed to be the original finish. A comparison in the National Automotive Paint File indicated that this finish was similar to that of 1941 Ford and Mercury automobiles. This information was promptly wired to the Chief of Police. The latter then submitted paint samples from a suspect 1941 Mercury for comparison with the original evidence.

The FBI Laboratory examiner was able to separate each layer of paint and, by means of microscopic, microchemical and spectrographic comparison examinations of the specimens, found them similar in colors, types, texture, layer structure and composition.

When local officers were advised that the samples from the suspect automobile corresponded with the paint chip found at the scene of the crime, the suspect was arraigned. He entered a plea of guilty.

If a bullet has no markings of evidentiary value, hairs and fibers adhering to it may have, in which case it will be sent to the Hairs and Fibers Unit for examination with respect to identifying the items for comparison purposes.

In one such instance an officer in a Midwestern city surprised two men in the act of blowing a safe. He ordered them to come out. Instead of complying with his orders, the men ran and the officer fired twice as the fleeing burglars made their exit through the door. Shortly thereafter, a bullet was recovered in the immediate area. Adhering to it were two small pieces of cloth and some fibers. A suspect, suffering from a wound obviously inflicted by a bullet, was located not far distant. He had been held up and shot, he said.

Skeptical authorities forwarded the suspect's underwear shirt and sweater, together with the bullet and its attached bits of cloth and fibers, to the FBI Laboratory. The bullet was determined to be a .38-caliber "wad cutter." It did not have sufficient markings to positively identify it as having come from the officer's gun, but one of the pieces of cloth adhering to the bullet in question matched in all observable microscopic characteristics, both as to thread and knit, the material from the undershirt of the suspect. In addition, the piece of cloth fitted perfectly in the hole left in the undershirt. The second piece of cloth removed from the bullet was found to be the same color, type, and weave as that of the sweater worn by the wounded man. The fibers wound around the nose of the bullet were human-body hairs similar to hair from under the arm.

Confronted with the evidence, the suspect pleaded guilty to the charges against him. He was sentenced to serve from one to ten years in prison.

The Serology Section of the FBI Laboratory is devoted to the study of body fluids. It is in this section that dried blood specimens can be classified as to whether they are of human or animal origin. The prosecution of case after case has been materially assisted by examinations conducted in the Serology Section. It follows, too, that in this, as in the other sections of the FBI Laboratory, the technician's examination serves equally to establish innocence as well as to point out guilt.

FIG. 5. General view of the Serological Section of the FBI Laboratory, Washington, D. C.

It is in the Petrographic Section of the FBI Laboratory that natural and artificial mixtures of minerals are compared and identified. Studies of soils and safe insulations have proved to be of immense value to the peace officer.

Although the variety of evidence received in the FBI Laboratory is enormous, the tremendously technical scientific instruments—X-ray equipment, spectrographs, spectrophotometers, and related equipment—have the versatility, in the hands of experienced examiners, to cope with a tremendous volume and variety of problems.

The fact that scientific instruments available to us are constantly being improved, coupled with the fact that the background of each Agent examiner is developing continuously, definitely indicates that the

laboratory will be of constantly increasing value to the law-enforcement officer in the future. That which was a difficult and intricate problem yesterday may today be simple routine.

Advances in the scientific field, and their adaptation to law-enforcement work, however, would have little meaning but for the corresponding advances at every level of law enforcement.

Of what use could the finest laboratory be if the officer in the field were ignorant of types of evidence which lend themselves to laboratory examination, and of methods of preserving and transmitting that same all-important evidence? Fortunately, today's officer no long is handed a stick, a badge and a gun and told to go forth and enforce the law. The average force today is comprised of men who have survived a rigid selective process, followed by a most intensive course of training. These two factors largely are responsible for law enforcement's swift advance toward a professional basis. They are also the reason why the miracles of modern science can be adapted with continuously increasing success to the field of law enforcement.

Chest X-Rays for Detection of Lung Cancer.—Value of chest X-ray surveys in detection of lung cancer was questioned recently by the director of such surveys for Philadelphia. Speaking at the University of Wisconsin Medical School, Dr. Katharine R. Boucot said that in the light of "dismal" success in surveys in Philadelphia, every effort should be made to develop new techniques to detect lung cancer while the disease is still in its primary stage. Dr. Boucot is professor of preventive medicine and clinical professor of medicine at Women's Medical College of Pennsylvania.

Surveys fail to indicate the presence of cancer early enough to be of significant value, Dr. Boucot said. In those cases detected by X-ray in Philadelphia, 70 per cent were inoperable because of the nature and widespread involvement of the cancer. Short-term survival rate of those who were operated on was only 20 per cent. Worse still, the five-year survival rate was only 5.5 per cent.

The two areas in which X-ray surveys may be of value are where the cancer is lying at the outer edges of the lung and where suspicious lung tissue is seen in persons who exhibit none of the symptoms of cancer, she explained.

Dr. Boucot urged that men over 45 without respiratory symptoms should report meticulously for survey films every six months. Any X-ray abnormality in men over 45 should be suspected of representing lung cancer. Even when active tuberculosis has been proven, the possibility of concurrent lung cancer should be considered, she added.

Dr. Boucot described a systematic survey which has been set up in Philadelphia. The Philadelphia Pulmonary Neoplasm Research Project's purpose is to evaluate the roles of symptoms and X-ray abnormalities.

"Every man who walks into the Philadelphia TB and Health Association Central Unit is automatically referred for interview and X-ray," she said. "If he has either film abnormality or significant symptoms, he is recalled for physician interview."

She pointed out that the symptoms considered are cough, worsening cough, blood spitting, wheezing in one lung, or weight loss of more than 10 pounds. In correlating symptoms and cancer cases, worsening cough and weight loss were found most significant.

In the first 3000 persons surveyed 21 proved cases of cancer were found.

"It is of interest in passing to point out that not one of the 21 cancer cases occurred among the 650 non-smokers or occasional smokers surveyed," Dr. Boucot said. "But this is not statistically significant although in accordance with the thinking of a lot of people around the country."

Two Radio "Nebulae" Discovered.—Announcement was made recently that two radio "nebulae" were detected by the 600-in. radio telescope recently installed at the Naval Research Laboratory. Measurements were made at a wave-length of 9 cm. (approximately 4 in.), corresponding to a frequency of 3200 megacycles. One of the new radio nebula is the Great Nebula of Orion, about 1000 light years from the earth, and the other is the "Swan Nebula," about 3000 light years away. Measurements were also made of several of the brighter radio sources in our Galaxy, and also one in the Constellation of Cygnus, which is about 30 million light years distant. The measurements reported represent the first successful investigation of wavelengths shorter than 21 centimeters.

THE SYNTHESIS OF SEQUENTIAL SWITCHING CIRCUITS*

BY

D. A. HUFFMAN [1]

PART II †

V. GENERALIZATION OF THE SECONDARY RELAY ASSIGNMENT PROBLEM

On the Number of Secondary Relays Required

For s secondary relays there are 2^s secondary relay states available for assignment to the rows of the flow table. Since we want each of the n rows of the flow table to be assigned a separate and distinct secondary relay state, there must be at least as many secondary relay states available as there are rows in the table. In other words, it is necessary that $n \leqq 2^s$.

The least conceivable number of secondary relays which we shall need for the flow table will be called s_0; and s_0 will have the property that it is the least integer which satisfies the inequality above.

It can also be demonstrated, by actually specifying a circuit, that certainly no more than $2s_0 + 1$ secondary relays are necessary for the synthesis of a circuit which is described by a flow table with n rows.[12]

Derivation of Formalized Assignment Criteria

Rather than try to build up a cumbersome catalog of situations which may arise in the assignment of secondary relay states, we shall immediately point out some other objectives we seek in the synthesis of any relay switching circuits.

It is our purpose to design circuits in such a way that the relationships among the operate and release times for the various relays play no part in the circuit operation. This requirement eliminates the possibility of including critical race conditions in the properties of the synthesized circuit. Where no race conditions exist, it is always possible for circuit operation to occur in such a way that successive secondary relay states involve only *unit* changes of state: that is, changes in which a single secondary relay variable is modified (see, for example, Table IV and Fig. 4).

In a flow table in which only unit changes of secondary relay state are to occur, each uncircled entry "k" must lead to the circled entry

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* This paper is derived from a dissertation submitted in partial fulfillment of the requirements for the degree Doctor of Science at the Massachusetts Institute of Technology.

[1] Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

† Part I was published in this JOURNAL for March, 1954.

[12] See *The "$2s_0 + 1$" Realization*, page 284 of this paper.

"k" (in the same column of the table) by a succession of *adjacent* secondary relay states. We will say then that each uncircled "k" entry is *connected* to the circled "k" entry.

We shall call a *set* of secondary relay states *connected* if each member of the set can be connected to every other member of the set by at least one succession of adjacent states from the set. For example, in Table XXIV(a), the 8-set (for $k = 8$) is composed of the secondary relay states "100," "010," and "110." This 8-set is connected, since (for instance) the state "010" may be connected to the state "100" by the succession "010"–"110"–"100."

In the synthesis procedure, therefore, we wish to assign secondary relay states to the rows of the flow table *in such a way that each k-set is connected.* (There will be as many k-sets as there are circled entries.) This assures us that the τ matrix can be constructed in such a way that only unit changes of state are indicated.

An important fact to keep fixed in mind in assigning secondary relay states is that the adjacency of two states is not affected by making a given interchange of variables in the state designators, or by complementing corresponding variables in the two states. For instance, the two states "1011" and "1010" are adjacent. If we interchange the second and third variables in each state, we get "1101" and "1100," respectively, and these new states are still adjacent. If, instead, we complement the first variable in each of the original state designators, the results are "0011" and "0010," respectively, and again the modified states are adjacent.

The reasoning above tells us that once we have any solution to the problem of assigning secondary relay states to the rows of the flow table, then we may perform given interchanges of variables and/or complementations on any number of the secondary relay states, and still have a valid assignment.

An Ideal Situation for Assignment

The Problem Statement

Here we include a synthesis example in which the solution of the assignment problem is straightforward. Its purpose is to show some of the goals which we should strive for, even though—in the syntheses of most switching circuits—they will not be so readily reached.

The circuit we wish to synthesize has two input leads and four output leads (see Fig. 8). The input restrictions are such that only

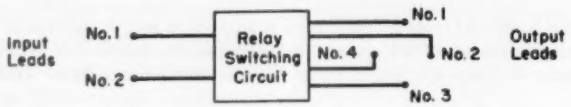

FIG. 8. A switching circuit to be synthesized.

one input lead may be grounded at a time, and so that neither input lead may be grounded unless both are first ungrounded. This latter restriction prohibits the transitions in input state from "01" to "10," and vice versa.

Of the four output leads, one—and only one—is to be grounded at a time. With the second input ungrounded, each grounding of the first input lead is to "advance" the position of the output ground by one step (clockwise on the schematic diagram). Removal of the input ground is to have no effect upon the output: for example, if initially both input leads are ungrounded and the No. 2 output lead is the one

TABLE XX.

(a)					(b)			
x:				Output	x:			
00	01	10	11	State	00	01	10	11
(1)	8	10		1000	(1)	8	10	
(2)	5	11		0100	(2)	5	11	
(3)	6	12		0010	(3)	6	12	
(4)	7	9		0001	(4)	7	9	
1	(5)			1000	1	(5)	(9)	
2	(6)			0100	2	(6)	(10)	
3	(7)			0010	3	(7)	(11)	
4	(8)			0001	4	(8)	(12)	
1		(9)		1000				
2		(10)		0100				
3		(11)		0010				
4		(12)		0001				

grounded, grounding of the first input lead is to remove the ground from the No. 2 output lead and impress the ground instead upon the No. 3 output lead. Subsequent removal of the input ground is to have no further effect on the output.

The grounding of the second input lead, on the other hand, is to make the position of the output ground "retreat" to the next counter-clockwise lead in the schematic diagram.

Our synthesized circuit is then to be a sort of "reversible counter"; a ground on one input lead is to have an effect opposite to that of a ground on the other input lead.

The Synthesis

A flow table corresponding to our problem statement is the one given in Table XX, Column (*a*). In it, no equivalences exist, but the mergers indicated in Column (*b*) may be made. In this latter flow table there are eight rows, and thus we know that at least three secondary relays will be necessary for a realization.

TABLE XXI.

(*a*) Flow Table

y: \ x:	00	01	10	11
000	(1)	8	10	
001	4	(8)	(12)	
010	1	(5)	(9)	
011	(4)	7	9	
100	2	(6)	(10)	
101	(3)	6	12	
110	(2)	5	11	
111	3	(7)	(11)	

(*b*) τ Matrix

y: \ x:	00	01	10	11
000	000	001	100	
001	010	000	000	
010	010	000	000	
011	000	100	001	
100	010	000	000	
101	000	001	100	
110	000	100	001	
111	010	000	000	

(*c*) Y Matrix

y: \ x:	00	01	10	11
000	000	001	100	(101)
001	011	001	001	(001)
010	000	010	010	(010)
011	011	111	010	(110)
100	110	100	100	(100)
101	101	100	001	(000)
110	110	010	111	(011)
111	101	111	111	(111)

(*d*) Z Matrix

y: \ x:	00	01	10	11
000	1000	1000	1000	(1000)
001	0001	0001	0001	(0001)
010	1000	1000	1000	(1000)
011	0001	0001	0001	(0001)
100	0100	0100	0100	(0100)
101	0010	0010	0010	(0010)
110	0100	0100	0100	(0100)
111	0010	0010	0010	(0010)

Since each k-set consists of just two members, we may make each such set connected if we assign adjacent secondary relay states to these two members. One assignment satisfying this restriction is that of Table XXI, Column (*a*). It is ideal in the sense that a change in state of no more than one secondary relay ever is required in passing from any circuit condition to any other. Further, this assignment can be

made without any modification of the flow table from the form given in Column (*b*) of Table XXI, other than reordering of its rows.

Clearly there will be many flow tables for which this fortuitous assignment may not be made. Nevertheless the operational advantages of this kind of assignment are such that any flow table should first be optimistically examined with the hope that it is a case of this type.

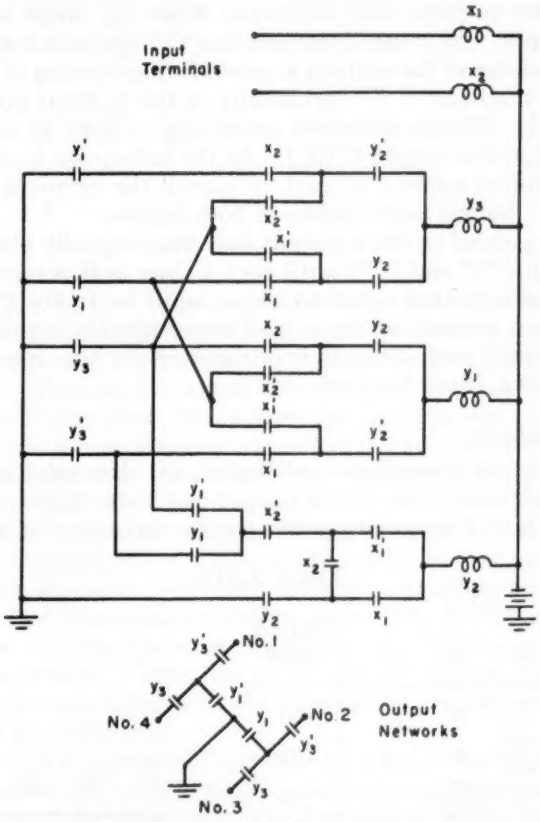

FIG. 9. The synthesized "reversible counter."

The τ and Y matrices were developed in the usual manner. The underlined entries of the Z matrix correspond to circled entries in the flow table and therefore are the output states associated with these entries. In order to simplify the output networks the additional entries in the Z matrix were chosen so that the output state does not change to its ultimate value until the proper secondary relay action has been completed.[13] The parenthesized entries in the Y and Z matrices corre-

[13] Contrast this procedure with that in *The Tables of Combinations and the Final Circuit*, Part I of this paper, page 180.

spond to non-occurring total relay states, and they were chosen to simplify the contact network structures in the circuit diagrammed in Fig. 9.

A Non-Ideal Situation for Assignment

The Problem Statement

The flow table in Column (*a*) of Table XXII describes a circuit which has two outputs, each somewhat under the direct control of its respective input. Starting from condition "1" (for which neither of the inputs and neither of the outputs is grounded) grounding of the x_1 input grounds the z_1 output ("3"); grounding of the x_2 input grounds the z_2 output ("2"). But simultaneous grounding of both x_1 and x_2 results in no ground at the output ("10"). In the latter case no possibility of an output ground exists ("8" and "9") until the circuit is returned to condition "1" by the ungrounding of both inputs.

In case a ground on the z_1 output lead was originally obtained ("3") it will remain ("5" and "7") until such a time as it is removed by the appearance of a ground signal on the x_2 input lead only ("8"). Similarly, in case a ground on the z_2 lead was originally obtained ("2") it will remain until such time as it is removed by the appearance of a ground on the x_1 input lead only ("9").

The Synthesis

Since all input transitions are allowed, the flow table is completely filled. Its minimum-row form is unique (see Table XXII, Column (*b*)) and at least $s_0 = 2$ secondary relays will be necessary for a realization.

TABLE XXII.

(*a*)

x: 00	01	10	11	Output State
(1)	2	3	10	00
6	(2)	9	4	01
7	8	(3)	5	10
6	2	9	(4)	01
7	8	3	(5)	10
(6)	2	9	4	01
(7)	8	3	5	10
1	(8)	9	10	00
1	8	(9)	10	00
1	8	9	(10)	00

(*b*)

x: 00	01	10	11
(1)	2	3	10
(6)	(2)	9	(4)
(7)	8	(3)	(5)
1	(8)	(9)	(10)

TABLE XXIII.

(*a*) Flow Table

y: \ *x*:	00	01	10	11
000	(1)	2	3	10
001	(6)	(2)	9	(4)
010	(7)	8	(3)	(5)
011				
100	1	(8)	(9)	(10)
101			9	
110		8		
111				

(*b*) τ Matrix

y: \ *x*:	00	01	10	11
000	000	001	010	100
001	000	000	100	000
010	000	100	000	000
011				
100	100	000	000	000
101			001	
110		010		
111				

Notice that the flow table requires that, in order to make the 1-, 2-, and 3-sets connected, the secondary state assigned to its first row be adjacent to the states assigned to its fourth, second, and third rows, respectively. Because no one of the four states (00, 01, 10, and 11) which are available from two relays can be adjacent to each of the other states, we know that two relays will not be sufficient for a proper secondary assignment. Therefore, for this flow table, at least three relays are necessary.

In actuality no proper assignment can be made to the flow table as it stands in Column (*b*) of Table XXII, regardless of how many secondary relays are used. We may recognize the dilemma which exists if we appreciate that each secondary relay state is either *even* or *odd*, depending on whether the state designator has an even or odd number of unity components. Thus, the state "10010" is even, while "10110" is odd. If two states (such as the two above) are adjacent, one must be even and the other odd.

In Table XXII, Column (*b*), therefore, if we choose to assign an odd state to the first row of the table, then the state associated with the second row must be even (since the 2-set must be connected and the two members of the set must then be adjacent). If an odd secondary relay state is associated with the first row of the table—as we have assumed—that associated with the fourth row must also be even, since the 1-set must be connected. But the second and fourth rows cannot both be assigned even states, since this makes it impossible for the two members of the 9-set to be adjacent.

The dilemma above may be bypassed if we *augment* the flow table by inserting additional "8" and "9" entries and if we assign the secondary states as shown in Column (*a*) of Table XXIII. The purpose

of augmenting the flow table in this way is to make both the 8-set and the 9-set connected. The corresponding partial τ matrix is that of Column (*b*).

Another possible solution to the assignment problem may occur if we do not make all possible row mergers in the original primitive table.

TABLE XXIV.

(*a*) Flow Table

y: \ x:	00	01	10	11
000	(1)	2	3	10
001	6	(2)	9	4
010	7	8	(3)	5
011				
100	1	(8)	(9)	(10)
101	(6)	2	9	(4)
110	(7)	8	3	(5)
111				

(*b*) τ Matrix

y: \ x:	00	01	10	11
000	000	001	010	100
001	100	000	100	100
010	100	100	000	100
011				
100	100	000	000	000
101	000	100	001	000
110	000	010	100	000
111				

For instance, the assignment made in Table XXIV is a valid one for our present example.

If we split the entries in each row of the table of Column (*b*) of Table XXIV and make the secondary state assignment of Table XXV, Column (*a*) (notice the symmetry about the dotted horizontal line), we obtain a flow table in which no more than one secondary relay need

TABLE XXV.

(*a*) Flow Table

y: \ x:	00	01	10	11
000	(1_1)	2_1	3_1	10_2
001	(6_1)	(2_1)	9_1	(4_1)
010	(7_1)	8_1	(3_1)	(5_1)
011	1_2	(8_1)	(9_1)	(10_1)
100	1_1	(8_2)	(9_2)	(10_2)
101	(7_2)	8_2	(3_2)	(5_2)
110	(6_2)	(2_2)	9_2	(4_2)
111	(1_2)	2_2	3_2	10_1

(*b*) τ Matrix

y: \ x:	00	01	10	11
000	000	001	010	100
001	000	000	010	000
010	000	001	000	000
011	100	000	000	000
100	100	000	000	000
101	000	001	000	000
110	000	000	010	000
111	000	001	010	100

TABLE XXVI.

(*a*) *Y* Matrix

y: \ *x*:	00	01	10	11
000	000	001	010	100
001	001	001	011	001
010	010	011	010	010
011	111	011	011	011
100	000	100	100	100
101	101	100	101	101
110	110	110	100	110
111	111	110	101	011

(*b*) *Z* Matrix

y: \ *x*:	00	01	10	11
000	00	00	00	00
001	01	01	01	01
010	10	10	10	10
011	00	00	00	00
100	00	00	00	00
101	10	10	10	10
110	01	01	01	01
111	00	00	00	00

change state in going from one circuit condition to another.[14] The τ, Y, and Z matrices corresponding to this latter assignment are given in Table XXV, Column (*b*) and Table XXVI. The final circuit diagram is shown in Fig. 10.

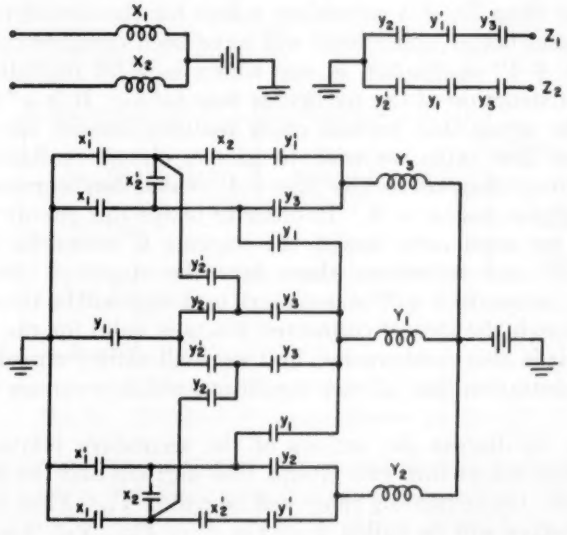

FIG. 10. The circuit derived from the flow table of Table XXV.

[14] It is easy to prove that *any* four-row table may be processed in the manner of this paragraph and that the resultant circuit is one in which a change in circuit condition requires, at most, a change of state of just one secondary relay. Inherent in such a proof is the conclusion that *any* four-row table may be realized in a circuit which uses three secondary relays.

VI. STANDARD CIRCUIT REALIZATIONS

Purpose

For some complex flow tables it may not be practically possible for the designer to find a solution to the problem of assigning secondary relay states, even though he knows (from the preceding section) what principles should guide him. For the general sequential circuit (with ultimately stable terminal action) the author knows of no definitive procedure which assigns secondary relay states to the flow table in such a way that all k-sets are connected, and so that a minimum number of secondary relays is used. Because of this fact it is valuable for a circuit designer to have at hand "standard" circuit realizations for the secondary relay control networks. The following two sub-sections demonstrate that such realizations exist, no matter what the form of the flow table may be.

The "$2s_0 + 1$" Realization

In this section we shall demonstrate that, for a flow table with n rows, a circuit can be designed which uses exactly $2s_0 + 1$ secondary relays.[15] Since, for the arbitrary flow table with n rows, no general method has yet been found which uses fewer relays, we must consider this as an upper limit on the number needed. If other design methods can be found which will be valid for any flow table and which will always require fewer than $2s_0 + 1$ secondary relays for the circuit realization, then a new and better upper limit will have been discovered.[16]

The "$2s_0 + 1$" realization is one which is valid regardless of the details of construction of the particular flow table. It is a "standard" circuit in the sense that certain main features remain the same, no matter what flow table we wish to give a circuit realization. The schematic circuit diagram for the "$2s_0 + 1$" realization is given in Fig. 11 for the particular case $s_0 = 3$. In order to adapt this circuit to a given flow table, we need only design the various C networks (and their complements) and substitute them into the standard circuit. The number of C networks it will be necessary to design will be the same as s_0.

Even though the idea of connected k-sets is valid for the "$2s_0 + 1$" realization, it is also cumbersome, and we shall satisfy ourselves with a direct demonstration that all race conditions which occur are noncritical in nature.

In order to discuss the actions of the secondary relays, we shall break up these relays into two groups (the α-group and the β-group) of s_0 relays each; the remaining relay will be called Y_0. Thus the $2s_0 + 1$ secondary relays will be called $Y_{\alpha 1}$, $Y_{\alpha 2}$, $\cdots$, $Y_{\alpha s_0}$, $Y_{\beta 1}$, $Y_{\beta 2}$, $\cdots$, $Y_{\beta s_0}$, and Y_0.

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[15] s_0 was defined in *On the Number of Secondary Relays Required*, this paper, page 275.

[16] In recent research the author has proved that $2s_0 - 1$ is always a sufficient number of secondary relays to implement a flow table. However, for relay circuits, this upper bound does not correspond to a simple standard circuit, as does the $2s_0 + 1$ bound. The results of this research will be published later this year.

It will be easier to demonstrate how a circuit can be constructed with $2s_0 + 1$ secondary relays if we work with an example. The example we have chosen is that of Table XXVII(a). Here there is a flow table of $n = 7$ rows and $2s_0 + 1$ is found to be equal to seven. The secondary relay states assigned have been indicated beside the rows of the table. Each secondary relay state, y, has been decomposed into components consisting of the states of the α-group of relays, those of the β-group of relays, and the state of the single relay, Y_0. In our example the notation for the secondary relay state is $y = (y_\alpha, y_\beta, y_0)$.

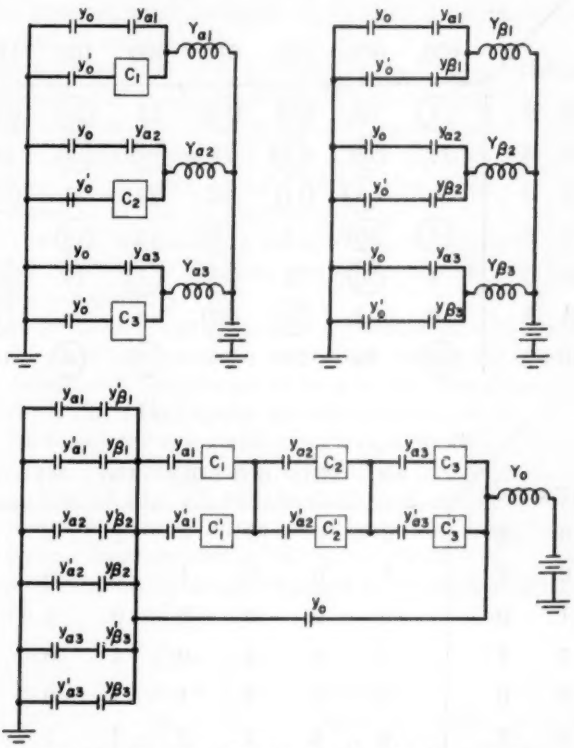

FIG. 11. The "$2s_0 + 1$" circuit realization (for $s_0 = 3$).

y_α and y_β represent the states of the α- and the β-groups of three (s_0) relays each, and y_0 is the state of the remaining relay. For instance, in the third row of the table in (a) of Table XXVII, $y_\alpha = y_\beta = 010$ and $y_0 = 0$.

We soon notice in (a) of Table XXVII that each secondary relay state, y, has been chosen of the form $y = (y_i, y_i, 0)$. In other words, each row has assigned to it a set of secondary relay states so that $y_\alpha = y_\beta$ and $y_0 = 0$. Since each of the α- and β-groups of relays has three (s_0) members, we may be sure that there are enough secondary relay states

$(y_i, y_i, 0)$ available to go around among the rows of the flow table. (The particular values of y_i assigned to the various rows of the table are completely arbitrary.)

A circuit can be constructed to utilize the assignment of secondary relay states which is given in Table XXVII(*a*). Figure 11 represents such a circuit. Especial attention should be paid to the construction

TABLE XXVII.—*A Flow Table and the Corresponding C_1 Network in Matrix Form.*

(*a*)

$y = (y_\alpha, y_\beta, y_0)$:	x: 000	001	010	011	100	101	110	111
000 000 0	(1)	10	(29)	(12)	13	(26)	(18)	16
001 001 0	21	(28)	(3)	17	(23)	(14)	18	(8)
010 010 0	9	(2)	(11)	12	23	14	(15)	(24)
011 011 0	(9)	(10)	3	(4)	13	(19)	7	24
100 100 0	1	(20)	11	(25)	(5)	19	(30)	8
101 101 0	9	2	(22)	(17)	5	6	(7)	(16)
110 110 0	(21)	20	22	4	(13)	(6)	15	(27)

(*b*)

$y_\beta = (y_{\beta 1}, y_{\beta 2}, y_{\beta 3})$:	x: 000	001	010	011	100	101	110	111
0 0 0	0	0	0	0	1	0	0	1
0 0 1	1	0	0	1	0	0	0	0
0 1 0	0	0	0	0	0	0	0	0
0 1 1	0	0	0	0	1	0	1	0
1 0 0	0	1	0	1	1	0	1	0
1 0 1	0	0	1	1	1	1	1	1
1 1 0	1	1	1	0	1	1	0	1
1 1 1								

of the contact networks controlling the relays in the α-group and in the β-group, and to that controlling the y_0 relay, because the form of these networks is the same no matter what the number of rows in the flow table with which we start.

In Fig. 11, the C networks are made up of contacts from the primary relays and of contacts from the β-group of secondary relays. Now we

shall investigate the construction of a typical C network. The motives behind this construction will be evident when circuit action is described later.

Each position in the flow table of (*a*) in Table XXVII corresponds to a fixed combination of $y_\beta = (y_{\beta 1}, y_{\beta 2}, y_{\beta 3})$ and of $x = (x_1, x_2, x_3)$. The matrix for each C network will be in terms of combinations of these values of y_β and x. In (*b*) of Table XXVII we have derived the entries in the matrix representation for the C_1 network. This network will be used later as a building block in forming the controlling network for the $Y_{\alpha 1}$ relay and also for the network which controls the Y_0 relay. (In general, the two-terminal network C_j is used in the control networks for the $Y_{\alpha j}$ and Y_0 relays.)

Suppose, for instance, that we wish to find the proper entry in the (110;011) position of the C_1 matrix. We should first look at the corresponding position in the flow table. It contains an uncircled "7." Notice now that the *circled* "7" is in a row corresponding to $y_{\alpha 1} = 1$. ($y_{\alpha 1}$ is the first component of y.) And so we make the entry in the (110;011) position of the C_1 matrix the digit "1." If we continue to fill in the C_1 matrix by inserting these ultimate values of $y_{\alpha 1}$, the result is (*b*) of Table XXVII. (The last row of the matrix may be completed in any arbitrary fashion.)

Now that we have given the rule for construction of the C networks in Fig. 11, we shall soon see the reason for specifying the networks in this way. Whenever the circuit is in a stable condition, our method of formation of the C networks assures that $C_1 = y_{\alpha 1}$, $C_2 = y_{\alpha 2}$, and $C_3 = y_{\alpha 3}$. And also, for any stable circuit condition, $y_{\alpha 1} = y_{\beta 1}$, $y_{\alpha 2} = y_{\beta 2}$, and $y_{\alpha 3} = y_{\beta 3}$. These restrictions, applied to the typical physical circuit configuration of Fig. 11, tell us that each of the seven secondary relays is in a stable state. Let us investigate now what happens as we change the circuit from condition "3" to condition "21." The starting point for our discussion of circuit changes is the stable circuit condition "3" for which

$$\begin{array}{lll} C_1 = 0, & C_2 = 0, & C_3 = 1, \\ y_{\alpha 1} = 0, & y_{\alpha 2} = 0, & y_{\alpha 3} = 1, \\ y_{\beta 1} = 0, & y_{\beta 2} = 0, & y_{\beta 3} = 1, \quad \text{and} \quad y_0 = 0. \end{array}$$

The flow table in (*a*) of Table XXVII indicates that a change of input state from "010" to "000" should result in the ultimate circuit condition "21." Of particular interest to us is the action of the various groups of secondary relays.

The method of building the C networks was such that, whenever the input state is modified, these C networks immediately assume transmissions corresponding to ultimate states of the relays in the α-group. In our example this means that change of the input state from "010" to "000" modifies the C network transmissions to $C_1 = 1$, $C_2 = 1$, and

$C_3 = 0$. These correspond to the value of $y_\alpha = 110$, which is associated with the circuit condition "21." We now have

$$\begin{array}{lll} C_1 = 1, & C_2 = 1, & C_3 = 0, \\ y_{\alpha 1} = 0, & y_{\alpha 2} = 0, & y_{\alpha 3} = 1, \\ y_{\beta 1} = 0, & y_{\beta 2} = 0, & y_{\beta 3} = 1, \quad \text{and} \quad y_0 = 0. \end{array}$$

This change in the transmission of the C networks assures that the relays in the α-group are now energized according to their ultimate states of operation (see Fig. 11). It can be observed that the relay Y_0, and the relays in the β-group are still in stable states.

After a time, all the relays in the α-group have reached their ultimate states of operation. Then

$$\begin{array}{lll} C_1 = 1, & C_2 = 1, & C_3 = 0, \\ y_{\alpha 1} = 1, & y_{\alpha 2} = 1, & y_{\alpha 3} = 0, \\ y_{\beta 1} = 0, & y_{\beta 2} = 0, & y_{\beta 3} = 1, \quad \text{and} \quad y_0 = 0. \end{array}$$

Y_0 becomes energized (see the controlling network for Y_0 in Fig. 11) just as soon as corresponding values of the transmissions of the C networks and the states of operation of the α-relays become equal—*and not before*. As soon as Y_0 becomes operated,

$$\begin{array}{lll} C_1 = 1, & C_2 = 1, & C_3 = 0, \\ y_{\alpha 1} = 1, & y_{\alpha 2} = 1, & y_{\alpha 3} = 0, \\ y_{\beta 1} = 0, & y_{\beta 2} = 0, & y_{\beta 3} = 1, \quad \text{and} \quad y_0 = 1. \end{array}$$

Operation of Y_0 does not change the stability of the relays in the α-group. But just as soon as—*and not before*—Y_0 is operated, the β-relays become unstable. Eventually these β-relays will become operated in the same way as their counterparts in the α-group. Then

$$\begin{array}{lll} C_1 = 1, & C_2 = 1, & C_3 = 0, \\ y_{\alpha 1} = 1, & y_{\alpha 2} = 1, & y_{\alpha 3} = 0, \\ y_{\beta 1} = 1, & y_{\beta 2} = 1, & y_{\beta 3} = 0, \quad \text{and} \quad y_0 = 1. \end{array}$$

During the time before the states of operation of the β-relays match up with the corresponding states of operation of the α-relays, the transmissions of the various C networks will be changing, since they are functions of the transmissions of contacts on the β-group of relays. During this time the Y_0 relay is kept operated by the path to ground through its own y_0 contact. However, as soon as all β-relays are operated in the same pattern as the α-relays, Y_0 becomes de-energized and eventually unoperated. Now

$$\begin{array}{lll} C_1 = 1, & C_2 = 1, & C_3 = 0, \\ y_{\alpha 1} = 1, & y_{\alpha 2} = 1, & y_{\alpha 3} = 0, \\ y_{\beta 1} = 1, & y_{\beta 2} = 1, & y_{\beta 3} = 0, \quad \text{and} \quad y_0 = 0. \end{array}$$

All secondary relays are again in stable states and again $y_\alpha = y_\beta$ and $y_0 = 0$. The circuit is at last in condition "21" and this was the desired result.

The changes in secondary relay state which have been described in the preceding paragraphs can be summed up in the briefer graphical form in Table XXVIII. The heavy arrows indicate where race conditions exist, but we have demonstrated that these are not critical.

TABLE XXVIII.—*Secondary Relay Actions.*

y:	$(y_\alpha,$	$y_\beta,$	$y_0)$
	001	001	0
	↓	·	·
	110	001	0
	110	001	1
	·	↓	·
	·	·	·
	110	110	1
	110	110	0

The control network configurations in the circuit of Fig. 11 are characteristic of the "$2s_0 + 1$" realization. So also are the actions of the groups of secondary relays given in Table XXVIII. To sum up:

When the circuit is stable, then an input-state modification which leads to a circuit condition which is represented in a new row of the flow table produces secondary relay action, as given below.

1. The α-relays change to the "new" states.
2. The Y_0 relay operates.
3. The β-relays change to the "new" states.
4. The Y_0 relay releases again to its unoperated state.

The "One-Relay-Per-Row" Realization

An interesting realization of a sequential circuit results if each row of the flow table is associated with its own relay. Thus, for a table with n rows, there will be n secondary relays. For each stable circuit condition represented in the ith row of the table, the ith (and only the ith) secondary relay is to be operated. For example, we might assign secondary relay states to the flow table shown in Table XXIX.

We wish to specify controlling networks for the secondary relays so that when a stable circuit condition represented in the ith row of the table (and associated, therefore, with the ith secondary relay) is followed by a stable condition in the jth row, then the only intermediate secondary relay state is to be one in which both the ith and the jth (and only these) secondary relays are operated. For instance—in Table XXIX—if we want to pass from condition "3" to condition "21," the following secondary relay action will occur:

1. If the circuit is in condition "3," the total relay state is (010; 0100000).
2. If the input state is now changed to "000," then the total relay state immediately changes to (000; 0100000).
3. We wish the state in (2) above to be followed by the state (000; 0100001).
4. The next, and final, total relay state is to be (000; 0000001).

TABLE XXIX.—*A Flow Table.*

y: \ x:	000	001	010	011	100	101	110	111
1000000	(1)	10	(29)	(12)	13	(26)	(18)	16
0100000	21	(28)	(3)	17	(23)	(14)	18	(8)
0010000	9	(2)	(11)	12	23	14	(15)	(24)
0001000	(9)	(10)	3	(4)	13	(19)	7	24
0000100	1	(20)	11	(25)	(5)	19	(30)	8
0000010	9	2	(22)	(17)	5	6	(7)	(16)
0000001	(21)	20	22	4	(13)	(6)	15	(27)

In order to illustrate the general rule for formation of the secondary relay controlling networks, we shall design these networks for the second and seventh secondary relays; these are the relays associated with the circuit conditions "3" and "21," respectively.

The controlling networks for each of the secondary relays may be considered to be in the general form shown in Fig. 12. If the relay Y_i

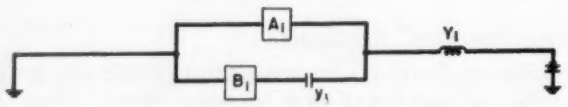

FIG. 12. Illustrating the design of secondary relay control networks.

is not operated, then the closing of the A network will result in its operation. On the other hand, if Y_i is operated and the A network is open, then opening the B network will result in the release of the relay to its unoperated state.

Let us now form the network Y_2. The A network is to be closed whenever any one of the following statements is true:

1. The input state is "010" and the fourth relay is operated.
2. The input state is "100" and the third relay is operated.
3. The input state is "101" and the third relay is operated.
4. The input state is "111" and the fifth relay is operated.

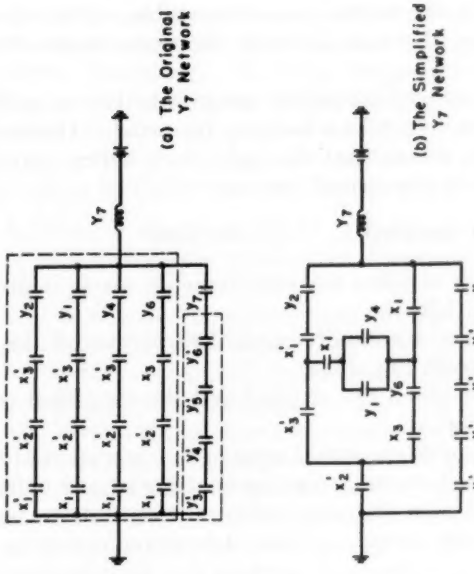

FIG. 14. Design of the Y_7 network.

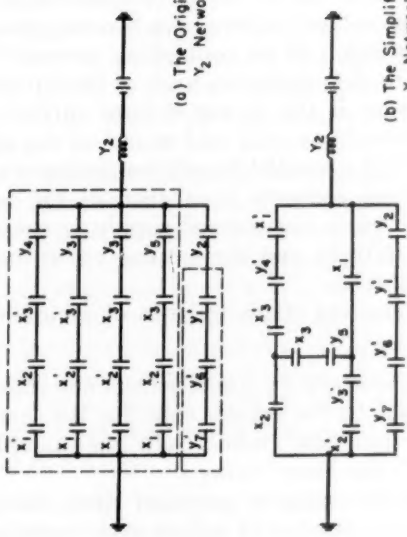

FIG. 13. Design of the Y_2 network.

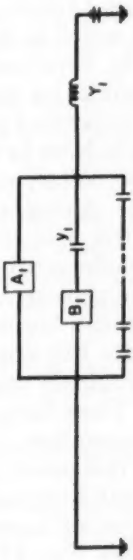

FIG. 15. A modified control network for the Y_1 relay.

Each condition above is one which ultimately leads to a stable circuit condition represented in the second row of the table. The circuit realization of the conditions above is given in the upper network of Fig. 13(*a*).

The *B* network for the second secondary relay is to be one which opens whenever other secondary relays become operated. However, inspection of the flow table shows that the only rows which may be entered from circled entries in the second row are:

(1) the seventh; (2) the sixth; (3) the first.

The circuit realization which satisfies the requirements above is given in the lower network of Fig. 13(*a*).

In Fig. 13(*b*) is a simplified terminally-equivalent version of the Y_2 network which is obtained from Fig. 13(*a*).

In Fig. 14(*a*) and (*b*) are given the original and the simplified control networks for the Y_7 relay.

One important practical problem would arise in the operation of the circuit which we have designed above. Assume that the supply voltage for the secondary relays has been disconnected from these relays—as it would be during a shutdown period. Then each secondary relay is unoperated and therefore $y_1 = y_2 = \cdots = y_7 = 0$. Examination of the networks controlling the secondary relays (those of Figs. 13(*a*) and 14(*a*) are typical) would reveal that the transmission of none of these networks can become unity until one of the secondary relays becomes operated. But none of these relays, in turn, can become operated (or even energized) until transmission of its controlling network becomes unity. These facts lead us to the conclusion that, as the circuit stands, proper operation cannot occur if the power is once turned off. To remedy this defect in the circuit, we may add to one of the secondary relay control networks (say Y_1) a parallel branch consisting of a cascade connection of normally closed contacts from each of the secondary relays (see Fig. 15). Now when the voltage supply is connected to the relays, Y_1 will operate initially and the ensuing circuit action can be that specified by the flow table.

There are two most interesting characteristics of a circuit derived in the manner above:

1. The maximum time necessary for transfer from one stable circuit condition to another is equal to the release time for the "old" relay, plus the operating time of the "new" relay. (In our example above, Y_2 is the "old" relay and Y_7 the "new" relay.)

2. Since only one secondary relay is operated when the circuit is stable, and since the greatest number of relays ever operated is two (and this is only a transient condition), then there is always very low current drain from the voltage supply.

VII. SUMMARY OF THE SYNTHESIS PROCEDURE

In the preceding sections we have developed a number of attitudes and procedures which have been useful in formalizing the steps of our synthesis procedure. We have demonstrated that the problem of designing a relay switching circuit with sequential and ultimately stable terminal action may be reduced to the equivalent problem of designing several combinational-type contact networks. The steps which we advise taking in the synthesis of a sequential relay circuit are these:

1. Make a statement of the problem in terms of a flow table in such a way that the specifications of the desired circuit action are exhaustively listed.

2. Investigate the conciseness of the problem statement and the possibility of simplification. We have proved that, for a flow table with "uniform vacancy" within each input-output set, the ultimate simplification will be unique.

3. Determine possible row mergers in the flow table so that the table may be shortened in length. We have proved that, for a circuit in which any input transition is possible, the form of the minimum-row condensed form of the flow table will be unique.

4. Assign secondary relay states to the rows of the flow table in such a way that all k-sets are connected. To make this assignment, it may be necessary to augment the flow table by additional uncircled entries. If desired, we may use the operation of row splitting as a supplementary tool.

5. Develop a τ matrix so as to realize the transitions indicated by the flow table. If we have made each k-set connected, the existence of at least one proper τ matrix is guaranteed.

6. Derive, by established procedure, a Y matrix corresponding to the τ matrix.

7. Place the output data in the Z matrix. If we wish the ultimate output state to appear as soon as possible after the input state is changed, we insert in each position of the Z matrix the output state associated with the corresponding numerical designator in the flow table, whether this designator be circled or not.

8. List the information in the Y and Z matrices in tables of combinations for the use of the designer of the static contact networks. With the initial assumptions we have made about the characteristics of the component relays, these secondary relay control networks and output networks will force the circuit to operate with the action specified by the original flow table.

In a particularly complex synthesis problem, we may find it impossible to solve by inspection the problem of assigning secondary relay states to the rows of the flow table; or we may wish to take advantage of the properties peculiar to one of the "standard" circuit realizations.

In this case, circuit realization may be made in terms of the "$2s_0 + 1$" circuit or of the "one-relay-per-row" circuit.

VIII. CRITIQUE OF MATERIAL ON SEQUENTIAL RELAY CIRCUITS, WITH EMPHASIS ON THE ROLE OF THE SECONDARY RELAY

The switching circuits we have considered in the preceding sections may be affected at any given time by some combination of several binary input variables, and these circuits may in turn act upon their surroundings by some combination of several binary output variables. Our main efforts have been to show that the operating requirements of a sequential (dynamic) switching circuit may be restated as a set of requirements for circuits with combinational (static) characteristics. These sequential requirements may be stated conveniently in a flow table.

The switching devices which we have used in the circuits of the preceding chapters have been relays. Some of these (the primary relays) are under the direct control of the input; the excitation of the others (the secondary relays) is a function of the states of operation of the various secondary relays as well as of the input state. In fact, we could *define* a secondary relay as one which is not under the direct influence of the input.

The output state of a sequential relay circuit may be a function of the states of operation of both the primary and the secondary relays. If there were no secondary relays, then the output would necessarily be a function of the input state only, and the circuit would not be a sequential one, but a combinational one. And so we may say that in a sequential circuit there must necessarily be devices (one or more) which are not under the direct control of the input. What is the function of these secondary devices?

Under the assumptions that we have made for the secondary relays —that all normally open contacts are either open or closed at the same time, and that the transmissions of all the normally closed contacts are always complementary to those of the normally open contacts—then only one property of such a relay seems to be necessary. This is: that a *time lag* should occur between its state of excitation (energization) and its state of response (operation). If we were to rob the secondary relays of this property, we could never put one into an unstable state, and there could never be step-by-step transitions between the various internal circuit configurations. We may say that, from a theoretical point of view, the time lag between the excitation and the response of the various secondary relays is a property *sufficient* to insure proper operation of the sequential relay circuits. This statement is evident if one agrees to the validity of the individual steps taken in the synthesis proposed in the earlier sections of this paper.

From an operational point of view, the relay circuit designer knows that the assumption of complementary transmission for the normally

open and normally closed contacts on a relay is not altogether valid. If the "complementary transmission" assumption is not valid, then it may be that the transmission of the contact network which excites some secondary relay, Y_i, may change value several times before arriving at the transmission dictated by the existing total relay state. This non-ideal situation creates what the relay circuit designer knows as an operating *hazard*. Such a hazard would be potentially undesirable if the response time (the operate time or the release time) of the relay Y_i were smaller than the time required for the transmission of the controlling network to settle down at its proper value. For then the response of Y_i would not be that intended by the designer, and improper operation of the over-all circuit might result.

Fortunately a finite amount of time (the response time) is necessary before the amount of energy in the magnetic field of a relay changes enough to change the state of operation of the relay. This *smoothing* effect tends to decrease the importance of an operating hazard. To eliminate the importance of a hazard altogether, the smoothing effect should be large enough that the response time of each secondary relay is greater than the *hazard time* of its controlling network.

Another property which is inherent in each relay may be termed that of *requantization*. By this term we mean to emphasize that the ultimate response of a relay is two-valued (because of the two-valued nature of the transmissions of its contacts), even though the magnitude of its magnetic field changes continuously in accordance with the "smoothed" excitation. This requantization property prevents corruption of the ground signals as they are handled by the secondary relays.

We may state the following conclusions:

1. Ideally, it is necessary and sufficient that there be a non-zero time between the excitation and response of a secondary relay.
2. Practically, it is important that a secondary relay also have the properties of excitation-smoothing and of requantization of this smoothed excitation as a two-valued output.

If we were to endow the secondary relay with human attributes, we could say that each one is a *decision-making* element. After each change in stimulation from its environment, it waits a time to "decide" what the final stimulation is to be, and then reacts accordingly. The operating "hazard" occurs when this "yes-no" decision is based on observation over an insufficient length of time.

IX. THE SYNTHESIS OF ELECTRONIC SWITCHING CIRCUITS

Electronic switching circuits have been more and more used in recent years, particularly in applications such as calculating machinery, where their speed of operation and lack of moving parts place them at a distinct advantage over relay switching circuits. The underlying prin-

ciples of electronic switching circuits are, however, the same as those we investigated in relay circuits, and these similarities will be pointed out in this section.

Combinational and Sequential Circuits

An electronic switching circuit may be combinational or sequential in nature just as a relay circuit is. A "combinational" network will refer to an electronic circuit which has several input leads upon which various combinations of "high" or "low" voltages may be impressed, and one or more output leads upon which, at a given time, either a "high" or "low" voltage appears. For a combinational network the functional dependence of an output voltage on the input voltages may be expressed by the entries in a table of combinations. (See, for example, Fig. 16.) On the other hand, a flow table will be used to describe the terminal characteristics of a sequential electronic switching circuit.

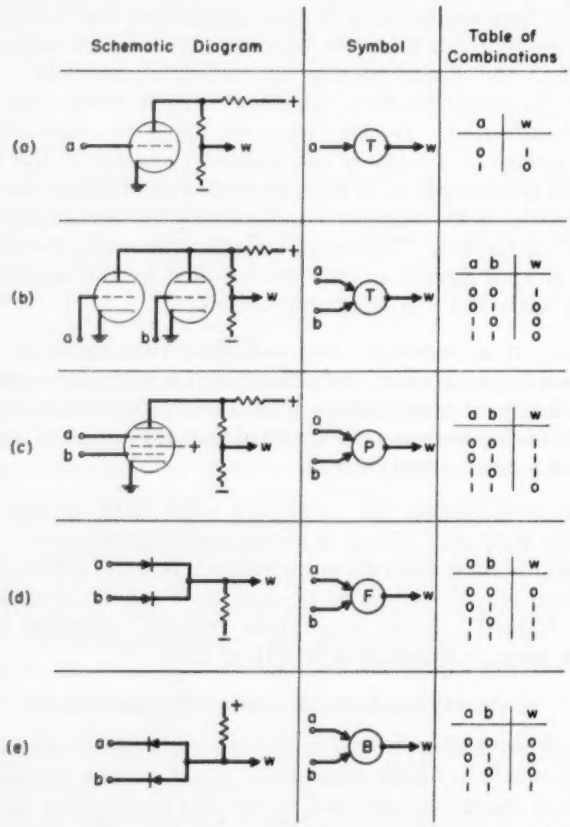

FIG. 16. Basic electronic combinational networks.

There is a variety of ways of giving an electronic realization to the requirements listed in a table of combinations. We will limit ourselves to circuits using standard vacuum-tubes (triodes and pentodes) and simple rectifiers. In Fig. 16 are listed five of the most used configurations of vacuum-tubes and rectifiers along with their associated tables of combinations and the symbols which will be used to represent them in this paper. These basic circuits and others are commonly used as building blocks for more complex networks. It is to be expected that, as research on them progresses, other devices, such as transistors and special-purpose switching tubes, will be utilized in building combinational networks.

The variables used in describing electronic switching circuits represent voltages. Such a voltage may be either "high"—in which case the variable is assigned a value of "1"—or "low," and then the variable is given the value "0." (Just how high "high" is and how low "low" is will be discussed below.)

The single triode is the most common way of complementing a two-valued voltage. When its input voltage is low (low enough to cut off the plate current) the output voltage is high, and when the input voltage is high (high enough to cause appreciable plate current to flow) the output voltage is low.

For the common-plate triode pair the output voltage is high only if both input voltages are low. For the pentode the output voltage is low only if both inputs are high.

The "forward" rectifier connection has the property that its output voltage is low only if both input voltages are low (lower than the voltage to which the associated resistor is returned). For the "backward" rectifier connection a high output results only when both inputs are high (higher than the voltage to which the associated resistor is returned).

There have been several papers written about the realization of combinational type networks using tubes and rectifiers. The book by Professor H. H. Aiken and his associates at Harvard University[17] represents the most notable original contribution in this field. The author cannot attempt to improve upon the excellent material presented there.

In this same book there appears, under the heading of "Triggers, Rings, and Digit Counters" (Chapter 8), an approach to the sequential circuit problem. This approach cannot be satisfying to this author because it fails to take into account the consequences of excitation and response not being identical, either physically or algebraically. Let us emphasize again that the fact of instability in a switching device arises from the distinction which we must make between excitation and response, and a sequential circuit can be designed properly only by the successful control of this instability.

[17] Staff of the Computation Laboratory, "Synthesis of Electronic Computing and Control Circuits," Cambridge, Harvard University Press, 1951.

Just as in our previous work with relay circuits our synthesis method for electronic switching circuits consists of a listing of the circuit requirements in a flow table and then a reduction of these requirements to a set of specifications for several combinational circuits. All of the techniques for manipulation of flow tables, assignment of secondary response states, and derivation of the τ, Y, and Z matrices are just as valid for electronic circuits as they are for relay circuits. It is only the physical realization of the Y and Z matrices that is different for the two types of circuits. The simple example of the next section will illustrate the underlying similarities and the physical differences involved.

The Synthesis Procedure Applied to a Simple Problem

Let us synthesize an electronic switching circuit which will have two input leads and two output leads. Assume that the voltages on the two input leads may not change simultaneously. The requirements (listed in the flow table of Table XXX(a)) for the circuit are these: A low voltage is to appear on both output leads if either of the input voltages is low (conditions "1," "2," and "3"). A high voltage is to appear on the Z_1 output lead (condition "4") only if both input voltages are high and if, just previously, only the X_1 input voltage was high. Similarly, the Z_2 output voltage is to be high only if both input voltages are high and if, just previously, only the X_2 input voltage was high.

The flow table listing these requirements may be condensed as shown

TABLE XXX.

(a) Primitive Flow Table

x: 00	01	10	11	z:
(1)	2	3		00
1	(2)		5	00
1		(3)	4	00
	2	3	(4)	10
	2	3	(5)	01

(b) Condensed Flow Table

x: 00	01	10	11
(1)	2	(3)	(4)
1	(2)	3	(5)

(c) τ Matrix

y: \ x:	00	01	10	11
0	0	1	0	0
1	1	0	1	0

(d) Y Matrix

y: \ x:	00	01	10	11
0	0	1	0	0
1	0	1	0	1

(e) Z Matrix

y: \ x:	00	01	10	11
0	00	00	00	10
1	00	00	00	01

in Table XXX(*b*). The secondary assignment and derivation of the τ, Y, and Z matrices are straightforward and are the same as if the synthesis were of a relay circuit. The final result of the synthesis procedure is the listing of the requirements for three electronic combinational networks (the Y, Z_1, and Z_2 networks). One possible circuit utilizing networks designed from these requirements is given in Fig. 19. Intermediate steps in its derivation are given in Figs. 17(*a*) and 18(*a*). These intermediate steps will be explained below.

Generation of Secondary Excitation and Response Voltages

Let us concentrate our attention on the Y excitation network. There are a variety of ways in which it may be designed, and four of these are given within the dotted-line limits of the symbolic diagrams of Fig. 17. The design of these combinational networks is an extensive

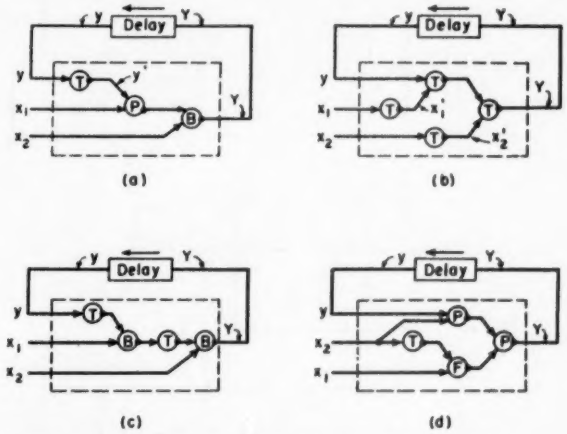

FIG. 17. Symbolic diagrams of four equivalent networks.

subject in itself and the reader is referred to the Harvard University text for further information on it.

Notice that the secondary excitation voltage, Y, is produced by (is a function of) the three voltages x_1, x_2, and y. Notice also that the response voltage, y, is made to lag the excitation voltage, Y, and that the connection which accomplishes this delay also creates a sort of feedback loop in the circuit. (It may be proved that, for proper circuit action, the voltage gain around the loop created must be greater than unity.) Usually it is not necessary to add the delay indicated, because some delay already exists around the loop due to distributed capacity, lead inductance, and the electron transit times within the vacuum tubes. However our analysis shows exactly at what point delay should be added if this addition becomes necessary.

It is clear from the diagrams of Fig. 17 that in electronic circuits designed by our synthesis methods there may not be a *device* which is analogous to the secondary relay of preceding sections. Instead, as in our present example, we may have to think about *secondary delay locations*. Thus, for example, the number s_0, which has been defined earlier in this paper,[18] will refer in electronic circuits to the minimum conceivable number of secondary delay locations necessary to realize a given

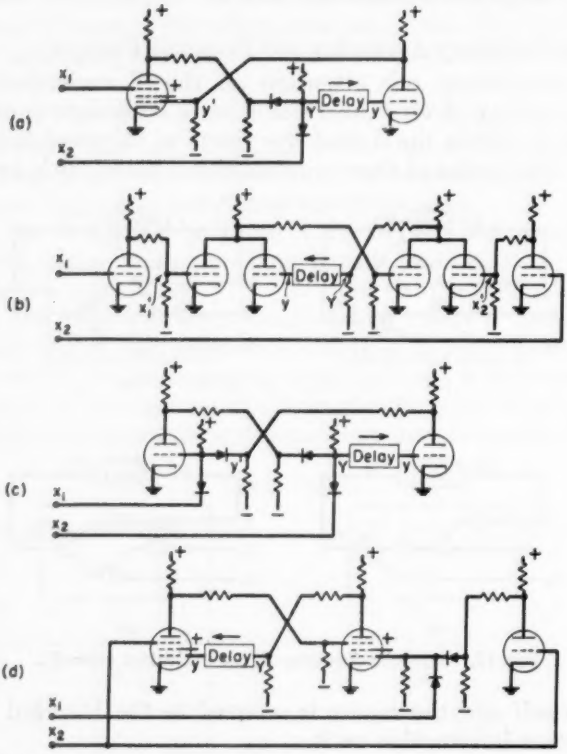

FIG. 18. Schematic diagrams of four equivalent networks.

flow table; at these delay locations there may not be a switching device, and perhaps it may not even be necessary to add additional delay at such points.

It is true that when feedback loops are added in the symbolic diagram they—in conjunction with the associated combinational networks—often produce interconnections of rectifiers and vacuum tubes which may be recognized as familiar. For example, observe the schematic diagrams of Fig. 18. (These correspond to the symbolic diagrams of

[18] See *On the Number of Secondary Relays Required*, page 275 of this paper.

Fig. 17.) The two center triodes of Fig. 18(*b*) are seen to be connected as an Eccles-Jordan circuit. The adjacent triodes have often been called "puller" tubes. And, in Fig. 18(*c*) there appears a modification of the Eccles-Jordan circuit.

Let us emphasize here that the familiar-looking circuits of Fig. 18 have been *derived* as a *by-product* of our synthesis procedure; they were not used as a starting point for it. What should concern us is that correctly designed *combinational* networks will insure proper operation of the total electronic switching circuit. The derivation of "trick" circuits—even though interesting, and perhaps surprising—should be considered as an incidental matter.

Let us return briefly to the synthesis of our circuit. If we use the circuit of Fig. 18(*a*) to generate the secondary voltage, y (and its complement, y'), then additional rectifiers may be added in order to give the output voltages, Z_1 and Z_2. The final circuit, with the two Z networks added, is given in Fig. 19.

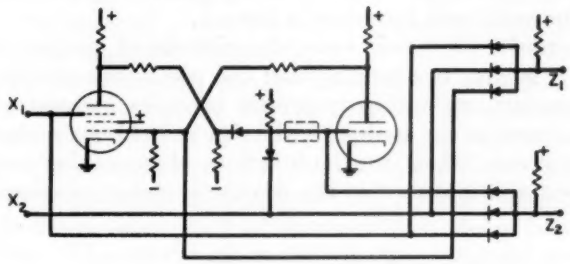

FIG. 19. The derived electronic switching circuit.

Comments on Treatment of the Eccles-Jordan Circuit

Since the Eccles-Jordan circuit is a commonly-used one, it may be of interest to examine whether or not the one of Fig. 18(*b*) is being used in the conventional manner. Let us consider what happens when both the X_1 and X_2 voltages are low. (This actually happens for circuit condition "1" listed in Table XXX(*a*).) Examination of the circuit diagram will show that, for these input voltages, the plate voltages on both of the two inner triodes (the Eccles-Jordan triodes) are low. This certainly is not the way that the Eccles-Jordan circuit is usually operated, but we see here that it is one possible (and here, useful) mode of operation.

Many of the algebraic inaccuracies this author believes exist in other methods which have been proposed for the treatment of Eccles-Jordan circuits arise directly from failure to recognize that the plate voltages of such a circuit are *not* algebraically complementary, since the possibility exists for both triodes of the pair to be conducting simultaneously.

Hazards

Since we have established a direct analogy between relay circuits and electronic circuits, it is natural to wonder what, in electronic circuits, is related to the "hazard" discussed for relay circuits. (See Section VIII.) It will be remembered that the possibility that a secondary excitation network might change its transmission several times before coming to the value dictated by the total relay state was termed a hazard. For electronic circuits the possibility that a secondary excitation network may give an excitation voltage which may change level (low to high, or high to low) several times before coming to the level dictated by the total circuit state will also, by analogy, be called a hazard.

For example, in Fig. 17(*d*) the voltage X_2 may be processed by the electronic devices along two separate paths before finally affecting the excitation voltage, Y. If the delays along these two paths are not the same, then the possibility for a hazard exists. In general, the existence of two or more parallel paths over which signals are processed in a combinational network may introduce a hazard.

As we consider electronic switching circuits of greater and greater complexity it is easy to visualize that the possibility of hazards in the various secondary excitation networks becomes increasingly serious. If we are to continue the analogy with relay switching circuits we should now ask ourselves: "How can the functions of smoothing and requantization be best accomplished at the secondary delay locations?"

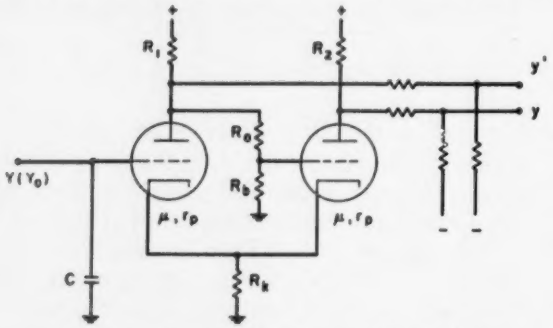

FIG. 20. A smoothing and requantizing device.

Elimination of the Effect of Hazards

A sufficiently large capacity will certainly accomplish the necessary smoothing if it is connected at the delay location. However it will also tend to corrupt the two-valued nature of the secondary response voltage there. On the other hand, it is easy to use a simple direct-coupled amplifier to accomplish the requantization of the secondary voltage but such a simple amplifier has practically no smoothing properties. If we

use a capacity in conjunction with the direct-coupled amplifier, an increase in the value of capacity required for smoothing makes it necessary that the gain of the amplifier also increase, in order to preserve the requantization property. What is needed is an amplifier with an effectively infinite gain and with a terminal at which the smoothing capacity may be connected without affecting this gain.

One relatively simple circuit which will have the properties needed is shown in Fig. 20. If the quantity

$$(R_1 + r_p)(R_2 + r_p) + R_k(\mu + 1)[R_1 + R_2 + 2r_p - \mu R_1 R_b/(R_a + R_b)]$$

is positive the circuit will have an infinite gain. (R_1 and R_2 represent the total resistive loading at each plate.) The circuit has the property that, for all practical purposes, the voltage at each plate is either "high" or "low" and does not assume intermediate values. If the voltage at the input grid varies continuously from a low value to a high value, at some critical intermediate voltage the voltage at the plate of the opposite triode will suddenly change from low to high. As the grid voltage decreases from its high value to its low value the same plate voltage will jump again to its low value.

If the input voltage to this device is some excitation voltage, Y, which has been smoothed by the capacity at the input grid, then the plate voltage described above can be used as the requantized response voltage, y. Its complement, y', appears at the other plate terminal.

In use in complicated switching circuits such a requantizing circuit would replace the delay lines at the secondary delay locations where hazards exist. The smoothing at each of these locations could be made as great as necessary to eliminate the effect of hazards by adding sufficient capacity at the input grid of the device.

Completion of the Analogy

In case this requantizing device (or some similar one) is used at each secondary delay location we will have a circuit completely analogous to one using relays. The voltage (high or low) from the electronic excitation network corresponds to the transmission (unity or zero) of the contact network exciting a relay; the smoothed excitation voltage corresponds to the magnetic field of the relay; the two complementary requantized response voltages correspond to the complementary transmissions of the normally open and normally closed contacts on the relay.

Acknowledgment

The author wishes to acknowledge his indebtedness to Professor S. H. Caldwell and to the students in the switching circuits course at the Massachusetts Institute of Technology for the willingness of their ears while the ideas presented in this paper were still in the rudimentary stage.

First Commercial Production of Vacuum Melted High Temperature Alloys.—James H. Moore, General Manager, has announced that Vacuum Metals Corporation of Cambridge, Mass., has begun the first commercial production of vacuum melted high temperature alloys and is expanding production of high purity nickel alloys for electronic tube construction. The continued high interest in Ferrovac-52100, a vacuum melted low-alloy steel, promises an increasing demand for this product in 1954. Vacuum Metals Corporation, a wholly owned subsidiary of National Research Corporation, and the first and only commercial source for vacuum melted alloys in the United States, has been engaged in the development of new metallurgical processes for the past ten years.

As a result of several years of research work, the interest in vacuum melted, high temperature alloys has been mounting rapidly. The research work begun in 1946 at Vacuum Metals Corporation has now borne fruit in the receipt of the first commercial quantity orders from jet engine manufacturers. The application of this vacuum melted product gives promise of not only better performance of the alloy in the engine but also increased ease of fabrication and higher yields. Since one of the principal obstacles in the way of continued improvement in gas turbine performance is the requirement for materials with improved high temperature properties, this development is of considerable importance.

During the past year there has been a continual increase in interest in vacuum melted high purity nickel, copper, and iron and dilute alloys of these metals for electronic tube components. In the first half of 1954, some of the alloys which have been hitherto produced on an experimental basis are being standardized for commercial production. Production tests have demonstrated very substantial increases in manufacturing yields of electronic tubes through the utilization of certain of these alloys. For this application, vacuum melting permits the precise control of very dilute alloying additions as well as of trace impurities to give tubes of improved dependability and performance.

New Radiation Detector.—Alpha Poppy is not the name of a flower or a new college fraternity, but the name chosen by General Electric engineers for a new radiation detector. It looks like the common conception of a futuristic ray gun, but it doesn't send rays; it "catches" them. The device is designed to check work areas and clothing for sources of alpha radiation, which can be dangerous if absorbed internally. Engineers of the General Engineering Laboratory explained that it will often be used with equipment that sends out warning "pops" when alpha contamination is detected; hence the odd name.

A tiny bit of radioactive material no larger than a pinhead will emit alpha particles for thousands of years. Since alpha radiation quickly dissipates its energy in air, it is normally harmless except when a source of such radiation becomes lodged inside the body.

The "muzzle" of the pistol-like Alpha Poppy is passed close over the areas of suspected contamination. Tissue-thin aluminum foil lets in alpha rays, but keeps out ordinary light.

The alpha rays are "caught" by a zinc sulfide screen, which causes them to expend their energy, creating light. The light is converted to electrical impulses, which are amplified thousands of times and can be used to obtain an audible or visible signal.

THE COULOMB FORCE AND THE AMPÈRE FORCE

BY

PARRY MOON[1] AND DOMINA EBERLE SPENCER[2]

ABSTRACT

The paper presents a preliminary study of electrodynamics based on an equation for the force between moving but unaccelerated charges. It is proved that the unique equation for force between current elements, consistent with a summation of forces between charges and the Ampère experiments, is Ampère's original equation.

The usual "Ampère equation" given in modern textbooks, however, is not the equation used by Ampère and cannot be derived from a force between moving charges. Since the modern treatment of the magnetic field stems from the so-called "Ampère equation," the entire electromagnetic theory obtained by the customary procedure is open to question.

1. INTRODUCTION

Early developments in electromagnetic theory were based on the force between charged particles (1).[3] The classical experiments (2) of Coulomb on the force between *stationary* charges were reported in 1785 and led to the well-known Coulomb equation. Gauss (1835) extended the equation to include the effect of *motion* of the charges (3). Grassmann (4) (1845), Weber (5) (1846), Helmholtz (6) (1873), Riemann (7) (1875), and others made contributions in the same spirit. Ampère's equation (1823) for the force between current elements (8) is likewise free of the field concept. All this work was founded directly on experimental data, without the introduction of a magnetic field.

The early formulations were superseded by the Faraday-Maxwell idea of electric and magnetic fields; and so successful were the Maxwell equations that the older formulation in terms of moving electric charges was almost forgotten. But the field equations encounter certain logical difficulties. In the first place, they violate the classical principle that absolute velocities are meaningless. In Maxwell's formulation, motion is referred to a "stationary" aether, c is a velocity with respect to the aether, and the presence or absence of a magnetic field depends on motion with respect to the aether.

Einstein's famous paper of 1905, "Zur Elektrodynamik bewegter Körper," which enunciated the theory of special relativity (9), was an attempt to remedy this non-relativistic aspect of electromagnetic theory. Looking back from the vantage point of present knowledge, we may wonder if Einstein's work was not directed up a blind alley. Instead

[1] Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

[2] Department of Mathematics, University of Connecticut, Storrs, Conn.

[3] The boldface numbers in parentheses refer to the references appended to this paper.

of adding an imposing façade to the shaky structure of Maxwell's theory, might it not have been better to examine the insecure foundations of the theory itself?

In most engineering applications, Maxwell's equations are perfectly satisfactory; but there are occasional ambiguities that have never been resolved (10, 11). Thus there is a growing feeling (12) that electromagnetic theory should be re-examined from the beginning.

One method of attack is to return to the basic formulations of Coulomb and Ampère and to examine possible modifications, in the light of modern knowledge. It seems likely that the entire subject of electromagnetism can be developed from an equation for the force between moving charges. This development would consider three aspects: (*a*) stationary charges (Coulomb's equation); (*b*) charges moving at constant relative velocity; and (*c*) accelerated charges. After the fundamental force-equations are obtained, the results may be expressed, for convenience, in terms of fields.

Part (*a*) was done by Coulomb. Part (*b*) deals principally with the forces exerted by direct currents. Part (*c*) is associated with alternating currents and electromagnetic waves. The present paper makes no attempt to deal with (*c*), but presents a study of the modification of Coulomb's equation that will satisfy Ampère's experimental results.

2. POSTULATES

The postulates needed in the logical development of an equation for the force between moving but unaccelerated charges are as follows:

Postulate A. Electrodynamics is truly relativistic—that is, absolute velocities are meaningless, and only relative velocities can appear in the equations.

Postulate B. The force between two moving charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. A function of angle and relative velocity also enters.

Postulate C. An electric current in a solid metallic conductor consists of a low-velocity drift of electrons, the positive charges remaining fixed with respect to the conductor.

Postulate D. The equation for force between moving charges (at low relative velocities) must yield an expression for force between current elements which satisfies Ampère's experiments.

Postulate E. The force between uncharged conductors is equal to the sum of the Ampère forces: between electrons, and between electrons and positive charges in the conductors.

3. FORCE ON A MOVING CHARGE

Consider two particles, having charges Q_1 and Q_2 (Fig. 1), separated by distance r. If there is no relative motion of Q_2 with respect to Q_1,

the force on Q_2, caused by Q_1, is adequately represented by Coulomb's equation,

$$\mathbf{F} = -\mathbf{a}_r \frac{Q_1 Q_2}{4\pi\epsilon r^2}, \tag{1}$$

where $\mathbf{a}_r$ is a unit vector in the direction from Q_2 to Q_1. The force given by Eq. 1 is called the *Coulomb force*. Since Q_1 and Q_2 are algebraic quantities, the force on Q_2 will be in the negative $\mathbf{a}_r$-direction if both charges have the same sign and in the positive $\mathbf{a}_r$-direction if the charges are of opposite sign. Throughout the paper, we shall use rationalized mks units; so forces are expressed in *newtons*, charges in *coulombs*, and distances in *meters*. The permittivity ϵ is in *farad* m^{-1}.

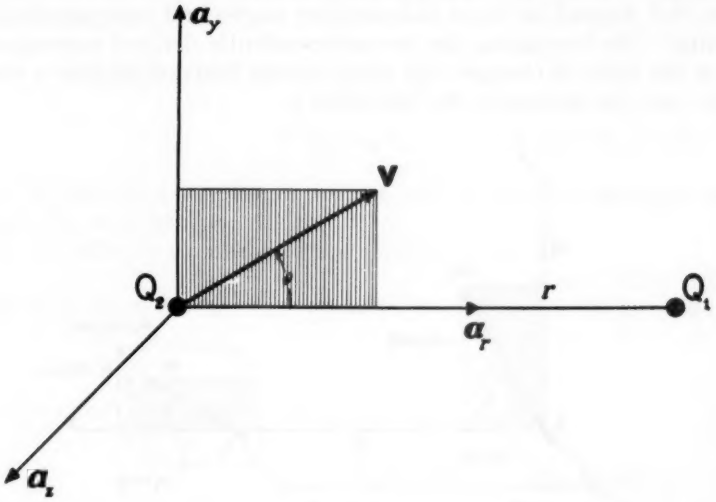

FIG. 1.

If Q_2 has a uniform velocity $\mathbf{v}$ with respect to Q_1, Eq. 1 is no longer adequate. An additional force occurs, and this additional force will be called the *Ampère force*. Consider the plane (Fig. 1) determined by $\mathbf{a}_r$ and $\mathbf{v}$. In this plane, we can introduce also the unit vector $\mathbf{a}_y$, which is obtained by rotating the vector $\mathbf{a}_r$ counterclockwise by $\pi/2$. A third unit vector $\mathbf{a}_z$ is perpendicular to the plane of the other two.

According to Postulate A, the relative velocity $\mathbf{v}$ is the only velocity that can appear in the equation for the Ampère force. Thus, by Postulates A, B, and C, the derived equation can contain only *five independent variables:* Q_1, Q_2, r, v, and θ. The Ampère force on Q_2 must be of the form

$$\mathbf{F}_2 = -\frac{Q_1 Q_2}{r^2} \Phi(v, \theta), \tag{2}$$

where $\Phi(v, \theta)$ is an unknown vector function. In terms of the components along the three axes of Fig. 1, Eq. 2 may be written

$$\mathbf{F}_2 = -\frac{Q_1 Q_2}{r^2}[\mathbf{a}_r f_r(v, \theta) + \mathbf{a}_y f_y(v, \theta) + \mathbf{a}_z f_z(v, \theta)]. \tag{3}$$

Equation 3 is the general form of expression for the Ampère force on a charge moving at constant velocity.

4. FORCE BETWEEN CURRENT ELEMENTS

The purpose of this section is to determine the functions f in Eq. 3. A pleasing characteristic of Eq. 3 is that it depends on only *one* angle and only *one* velocity. Equations for the force between current elements (13) depend on three independent angles and two velocities (or currents). By comparing the two independently derived expressions—one on the basis of charges, the other on the basis of Ampère's experiments—we can determine the functions f.

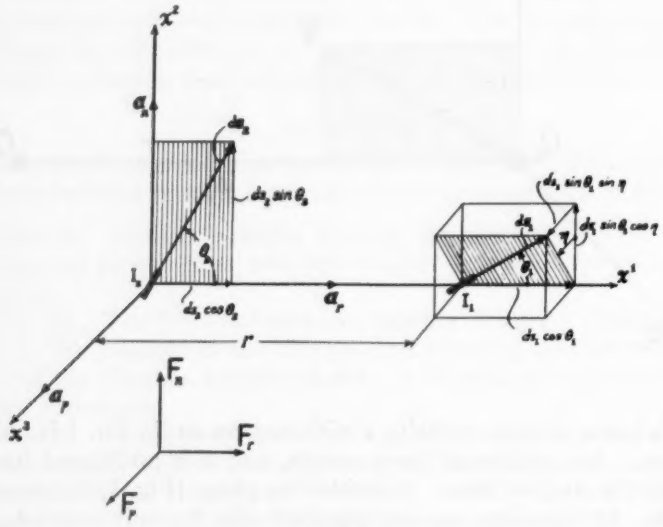

FIG. 2.

Consider two elements of wire with lengths ds_1 and ds_2 (Fig. 2). There is no motion of one element with respect to the other. If currents exist in the two conductors, each element contains stationary positive charges and moving negative charges (Postulate C). The velocities of the electrons, with respect to the conductors, are denoted by $\mathbf{v}_1$ and $\mathbf{v}_2$; and the Ampère force on element ds_2 is called $d^2\mathbf{F}_2$.

Let N be the number of free electrons per unit volume of conductor,

A the cross-sectional area, and $|Q_e|$ the magnitude of the electronic charge. Then the aggregate of free electrons on ds_2 constitutes a charge

$$Q_2 = -N_2A_2|Q_e|ds_2;$$

while the aggregate of positive charges (actually the difference between the total positive charge and the bound negative charge) on ds_1 is

$$Q_1 = +N_1A_1|Q_e|ds_1.$$

Consider first the Ampère force on ds_2, produced by the interaction of electrons in ds_2 and positive charges in ds_1. The magnitude of the relative velocity is $|\mathbf{v}| = v_2$, and the angle is $\theta = \theta_2 + \pi$. According to Eq. 3, therefore,

$$d^2\mathbf{F}_{+-} = +\frac{N_1N_2A_1A_2|Q_e|^2ds_1ds_2}{r^2}[\mathbf{a}_r f_r(v_2, \theta_2 + \pi) + \mathbf{a}_y f_y(v_2, \theta_2 + \pi) + \mathbf{a}_z f_z(v_2, \theta_2 + \pi)], \quad (4)$$

where the current I_2 makes an angle θ_2 with $\mathbf{a}_r$ but the electrons make an angle $(\theta_2 + \pi)$ with $\mathbf{a}_r$.

For electrons in ds_1 and positive charges in ds_2,

$$|\mathbf{v}| = v_1, \quad \theta = \theta_1, \quad Q_1 = -N_1A_1|Q_e|ds_1, \quad Q_2 = +N_2A_2|Q_e|ds_2,$$

and

$$d^2\mathbf{F}_{-+} = +\frac{N_1N_2A_1A_2|Q_e|^2ds_1ds_2}{r^2}\{\mathbf{a}_r f_r(v_1, \theta_1) + \mathbf{a}_y[f_y(v_1, \theta_1)\cos\eta - f_z(v_1, \theta_1)\sin\eta] + \mathbf{a}_z[f_z(v_1, \theta_1)\cos\eta + f_y(v_1, \theta_1)\sin\eta]\}. \quad (5)$$

For electrons in both conductors,

$$|\mathbf{v}| = |\mathbf{v}_2 - \mathbf{v}_1| = v_3, \quad Q_1 = -N_1A_1|Q_e|ds_1, \quad Q_2 = -N_2A_2|Q_e|ds_2,$$

and

$$d^2\mathbf{F}_{--} = -\frac{N_1N_2A_1A_2|Q_e|^2ds_1ds_2}{r^2}\{\mathbf{a}_r f_r(v_3, \theta_3) + \mathbf{a}_y[f_y(v_3, \theta_3)\cos\eta_3 - f_z(v_3, \theta_3)\sin\eta_3] + \mathbf{a}_z[f_z(v_3, \theta_3)\cos\eta_3 + f_y(v_3, \theta_3)\sin\eta_3]\}, \quad (6)$$

where

$$v_3^2 = v_1^2 + v_2^2 - 2v_1v_2(\cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2\cos\eta), \quad (7)$$

$$\begin{cases} \cos\theta_3 = \dfrac{1}{v_3}\,(v_1\cos\theta_1 - v_2\cos\theta_2), \\ \sin\theta_3 = \dfrac{1}{v_3}\,[v_1^2\sin^2\theta_1 + v_2^2\sin^2\theta_2 - 2v_1v_2\sin\theta_1\sin\theta_2\cos\eta]^{\frac{1}{2}}, \end{cases} \quad (8)$$

$$\begin{cases} \sin\theta_3\cos\eta_3 = \dfrac{1}{v_3}\,(v_1\sin\theta_1\cos\eta - v_2\sin\theta_2), \\ \sin\theta_3\sin\eta_3 = \dfrac{v_1}{v_3}\sin\theta_1\sin\eta. \end{cases} \quad (9)$$

There is no Ampère force $d^2\mathbf{F}_{++}$. So, by Postulate E, the total force on Q_2 is the sum of the forces given by Eqs. 4, 5 and 6, or

$$\begin{aligned} d^2\mathbf{F}_2 = \frac{N_1N_2|Q_e|^2ds_1ds_2}{r^2A_1A_2}\,\{&\mathbf{a}_r[f_r(v_1,\theta_1) + f_r(v_2,\theta_2+\pi) - f_r(v_3,\theta_3)] \\ &+ \mathbf{a}_y[f_y(v_1,\theta_1)\cos\eta + f_y(v_2,\theta_2+\pi) - f_y(v_3,\theta_3)\cos\eta_3 \\ &\qquad - f_z(v_1,\theta_1)\sin\eta + f_z(v_3,\theta_3)\sin\eta_3] \\ &+ \mathbf{a}_z[f_z(v_1,\theta_1)\cos\eta + f_z(v_2,\theta_2+\pi) - f_z(v_3,\theta_3)\cos\eta_3 \\ &\qquad - f_y(v_1,\theta_1)\sin\eta - f_y(v_3,\theta_3)\sin\eta_3]\}. \end{aligned} \quad (10)$$

According (13) to the Ampère Postulates I and II, the actual current elements may be replaced by components along the coordinate axes, and the force $d^2\mathbf{F}_2$ must be expressible in terms of the products:

$$\left.\begin{array}{l} I_1\cos\theta_1\,ds_1, \\ I_1\sin\theta_1\cos\eta\,ds_1, \text{ or} \\ I_1\sin\theta_1\sin\eta\,ds_1 \end{array}\right\} \times \begin{cases} I_2\cos\theta_2\,ds_2, \text{ or} \\ I_2\sin\theta_2\,ds_2. \end{cases}$$

But the magnitudes of the currents are

$$|I_1| = N_1A_1|v_1||Q_e|, \quad |I_2| = N_2A_2|v_2||Q_e|. \quad (11)$$

Thus each bracket of Eq. 10 must be equivalent to a sum of terms having the forms

$$\begin{aligned} &v_1v_2\cos\theta_1\cos\theta_2, \\ &v_1v_2\cos\theta_1\sin\theta_2, \\ &v_1v_2\sin\theta_1\cos\theta_2\cos\eta, \\ &v_1v_2\sin\theta_1\sin\theta_2\cos\eta, \\ &v_1v_2\sin\theta_1\cos\theta_2\sin\eta, \\ &v_1v_2\sin\theta_1\sin\theta_2\sin\eta. \end{aligned}$$

No other terms will satisfy the Ampère requirements.

We are now in a position to evaluate the functions f of Eq. 3. Since Eq. 10 must be made up of the above six possible forms, the most general expression for $f(v, \theta)$ will be

$$f(v, \theta) = \sum A_{mnq} v^m \sin^n \theta \cos^q \theta. \tag{12}$$

Substitution of Eq. 12 into the first bracket of Eq. 10 shows that the only possibilities that satisfy Postulates I and II are

$$(i) \quad m = 2, \quad n = q = 0;$$

$$(ii) \quad m = n = 2, \quad q = 0;$$

$$(iii) \quad m = q = 2, \quad n = 0.$$

The second and third brackets will not give allowable forms in any case

In (*iii*), for instance,

$$\begin{aligned} f(v, \theta) &= Av^2 \cos^2 \theta, \\ f(v_1, \theta_1) &= Av_1^2 \cos^2 \theta_1, \\ f(v_2, \theta_2 + \pi) &= Av_2^2 \cos^2 \theta_2, \\ f(v_3, \theta_3) &= Av_3^2 \frac{(v_1 \cos \theta_1 - v_2 \cos \theta_2)^2}{v_3^2} \\ &= A[v_1^2 \cos^2 \theta_1 + v_2^2 \cos^2 \theta_2 - 2v_1 v_2 \cos \theta_1 \cos \theta_2]. \end{aligned}$$

Thus the first bracket of Eq. 10 becomes

$$[f(v_1, \theta_1) + f(v_2, \theta_2 + \pi) - f(v_3, \theta_3)] = 2v_1 v_2 \cos \theta_1 \cos \theta_2, \tag{13}$$

which is an allowable form. But substitution in the other two brackets of Eq. 10 does not result in a permissible term.

The three possibilities are listed in Table I. Also, since $Av^2 = Av^2 \sin^2 \theta + Av^2 \cos^2 \theta$, there are only two independent cases.

TABLE I.—*Possible Functions.*

No.	$f(v, \theta)$	$[f(v_1, \theta_1) + f(v_2, \theta_2 + \pi) - f(v_3, \theta_3)]$
i	Av^2	$2Av_1v_2(\cos \theta_1 \cos \theta_2 + \sin \theta_1 \sin \theta_2 \cos \eta)$
ii	$Av^2 \sin^2 \theta$	$2Av_1v_2 \sin \theta_1 \sin \theta_2 \cos \eta$
iii	$Av^2 \cos^2 \theta$	$2Av_1v_2 \cos \theta_1 \cos \theta_2$

We conclude, therefore, that *the most general equation for the Ampère force on a charge* Q_2 is

$$\mathbf{F}_2 = -\mathbf{a}_r \frac{Q_1 Q_2 |v|^2}{r^2} [A \sin^2 \theta + B \cos^2 \theta]. \tag{14}$$

The corresponding equation for the force between current elements is obtained by utilizing Eq. 14 and Table I:

$$d^2\mathbf{F}_2 = \mathbf{a}_r \frac{|I_1| |I_2| ds_1 ds_2}{r^2} [2A \sin \theta_1 \sin \theta_2 \cos \eta + 2B \cos \theta_1 \cos \theta_2]. \tag{15}$$

This is the most general equation that can be obtained, subject only to the postulates of Section 2, Ampère Postulates I and II, and the requirement that the force be based on moving charges.

To introduce the other Ampère experiments and the behavior of parallel conductors, we need merely refer to the general expression derived in a previous paper (13):

$$\begin{cases} d^2F_r = \dfrac{|I_1|\,|I_2|\,ds_1\,ds_2}{r^2}\left[A_{111}\cos\theta_1\cos\theta_2 + A_{221}\sin\theta_1\sin\theta_2\cos\eta\right], \\ d^2F_n = \dfrac{|I_1|\,|I_2|\,ds_1\,ds_2}{r^2}\left[(A_{111} + A_{221} - \mu/4\pi)\cos\theta_1\sin\theta_2\right. \\ \qquad\qquad \left. + (A_{221} - 2\mu/4\pi)\sin\theta_1\cos\theta_2\cos\eta\right], \\ d^2F_p = \dfrac{|I_1|\,|I_2|\,ds_1\,ds_2}{r^2}\left[(A_{221} - 2\mu/4\pi)\sin\theta_1\cos\theta_2\sin\eta\right. \\ \qquad\qquad \left. + A_{123}\cos\theta_1\sin\theta_2 + A_{323}\sin\theta_1\sin\theta_2\sin\eta\right]. \end{cases} \quad (16)$$

Comparison of Eqs. 15 and 16 shows that

$$A_{111} = 2B = -\mu/4\pi, \quad A_{221} = 2A = 2\mu/4\pi, \quad A_{123} = A_{323} = 0.$$

Thus we obtain *uniquely* the Ampère force between moving charges:

$$\mathbf{F}_2 = -\mathbf{a}_r \frac{\mu Q_1 Q_2 |v|^2}{4\pi r^2}\left[1 - \tfrac{3}{2}\cos^2\theta\right] \quad (14a)$$

and the force between current elements:

$$d^2\mathbf{F}_2 = \mathbf{a}_r \frac{\mu |I_1|\,|I_2|\,ds_1\,ds_2}{4\pi r^2}\left[2\sin\theta_1\sin\theta_2\cos\eta - \cos\theta_1\cos\theta_2\right]. \quad (15a)$$

These are the only possible equations consistent with the Ampère Postulates I, II, III, IV, and the postulates of Section 2.

5. POSTULATES I, II, IV, V

Since Postulate III is less firmly established than the others (13), we might consider the possibility of its omission. The most general equation for the force between current elements, based on Postulates I, II, IV, and V is (13)

$$d^2\mathbf{F}_2 = \mathbf{a}_r \frac{|I_1|\,|I_2|\,ds_1\,ds_2}{r^2}\left\{A_{111}\cos\theta_1\cos\theta_2 + \left(\frac{3\mu}{8\pi} - \frac{A_{111}}{2}\right)\sin\theta_1\sin\theta_2\cos\eta + A_{321}\sin\theta_1\sin\theta_2\sin\eta + A_{211}\left[\sin\theta_1\cos\theta_2(\sin\eta + \cos\eta) - \cos\theta_1\sin\theta_2\right]\right\}. \quad (17)$$

Comparison of Eqs. 15 and 17 shows that $A_{111} = 2B$, $A_{321} = A_{211} = 0$, $2A = \frac{3\mu}{8\pi} - B$. Thus Eqs. 14 and 15 become

$$\mathbf{F}_2 = -\mathbf{a}_r \frac{Q_1 Q_2 |v|^2}{r^2}\left[\frac{1}{2}\left(\frac{3\mu}{8\pi} - B\right)\sin^2\theta + B\cos^2\theta\right], \qquad (14b)$$

$$d^2\mathbf{F}_2 = \mathbf{a}_r \frac{|I_1|\,|I_2|\,ds_1\,ds_2}{r^2}\left\{\left(\frac{3\mu}{8\pi} - B\right)\sin\theta_1 \sin\theta_2 \cos\eta + 2B\cos\theta_1\cos\theta_2\right\}, \qquad (15b)$$

which are the most general expressions obtainable with the omission of Postulate III and the inclusion of Postulate V.

We now introduce the requirement that a steady direct current in a closed circuit shall induce no emf. in another circuit. This requirement can be simplified by considering the force on a single electron, caused by d.c. in a loop. Proceeding as in Section 4 of the previous paper (13), we find that a zero force on the electron requires the Ampère equation. This same condition is necessary if the force on a bound positive charge (and therefore the longitudinal force on a conductor) is to be zero. Thus Postulate III and the necessity of zero induced emf. are essentially equivalent, and Ampère's equation remains unique.

6. CONCLUSIONS

A previous study (13) showed that there are ∞^4 possible equations for the force between current elements, all satisfying the Ampère experiments. Among these possible equations are those advocated by Ampère, Grassmann, Clausius, and Korteweg. But when we introduce the additional requirement that the force between current elements be derivable from the force between moving charges, we find that there is *only one possible equation*, which proves to be Ampère's original equation (8). The corresponding equation for the Ampère force between charges is Eq. 14*a*. The complete force on an unaccelerated charge is the sum of the Coulomb force and the Ampère force, or

$$\mathbf{F}_2 = -\mathbf{a}_r \frac{Q_1 Q_2}{4\pi\epsilon r^2}\left[1 + \left(\frac{v}{c}\right)^2 (1 - \tfrac{3}{2}\cos^2\theta)\right]. \qquad (18)$$

Equation 18 applies only at low velocities ($v^2 \ll c^2$).

Surely, any modern treatment of electrodynamics must agree with the known facts about electrons and electronic conduction. Thus when one finds that the equations studied by Grassmann, Korteweg, and some other 19th-century physicists cannot be derived from a force between charges, he is justified in questioning these expressions. In

particular, many modern textbooks (14) give for the force between current elements,

$$d^2\mathbf{F}_2 = \frac{\mu I_1 I_2}{4\pi r^2}\left[(d\mathbf{s}_1 \times \mathbf{a}_r) \times d\mathbf{s}_2\right]. \tag{19}$$

The quantitative treatment of the magnetic field is then obtained by splitting Eq. 19 into two parts. Defining the concept of magnetic induction **B** by means of the equation

$$d\mathbf{B} = -\frac{\mu I_1}{4\pi r^2}(d\mathbf{s}_1 \times \mathbf{a}_r),$$

one obtains

$$d^2\mathbf{F}_2 = -d\mathbf{B} \times I_2\, d\mathbf{s}_2 = I_2\, d\mathbf{s}_2 \times d\mathbf{B}.$$

But Eq. 19 is not derivable from the force between charges. Thus *the equation is untenable, and the whole process of defining a magnetic field from this equation is unsound.*

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Vermiculite Carrier Solves Chelate Application Problems.—Serious application and handling problems of iron chelates have been solved by using vermiculite as a carrier, it was reported recently. Zonolite Company, Chicago, vermiculite producers, said the mica-like mineral has reduced fruit burning and leaching common when iron chelates are used alone to treat iron deficiency in plants.

A Zonolite official suggested this latest use of vermiculite may offer a solution to other chemical manufacturers seeking an effective carrier for their products.

As originally developed and used by Bersworth Chemical Company of Framingham, Mass., the chelates were in the form of a fine, dry, extremely hygroscopic powder. Applied to the soil by conventional spreader methods, the chelates produced a dust which settled on leaves and fruit, causing fruit "burn." Once in the soil, the chelates were quickly washed out and their efficiency spoiled by rain fall.

In their search for a carrier, Bersworth chemists tried vermiculite. They found the mineral readily absorbed the chelates in solution, resulting in a dry, granular material that flowed easily and was dust free. As a result, the chelates in vermiculite can be easily applied to the soil by ordinary methods. Vermiculite's multicellular structure regulates solubility by holding moisture and releasing it slowly to the soil as needed. Leaching is slow and persistent.

Addition of the carrier and packaging is done at Zonolite Company's mine and processing plant at Travelers Rest, S. C. Iron chelates in solution are absorbed by the vermiculite, approximately 27/70 mesh, and passed through a rotary dryer. The resulting greenish-brown granular mixture may be used as is, or mixed with recommended fertilizers. No special precautions, such as wearing masks, are needed.

New Station-Type Lightning Arrester.—A new station-type lightning arrester, called the Thyrite * "Magne-Valve" arrester, attaining 20 per cent lower IR discharge voltage, 10 per cent lower sparkover voltage and three times greater discharge capacity and endurance than the previous model, has been announced by the General Electric Company's Distribution Transformer Department, Pittsfield, Mass.

This Magne-Valve arrester combines *magnetic* action of a new type gap unit with *valve* action of Thyrite material. What has been described by G–E engineers as a revolutionary design of gap unit includes parallel sets of gap electrodes connected in series with magnetizing coil. This gap unit has a lightning sparkover path across one gap, but has the arc-interrupting path across as many as 14 multi-gaps. The engineers said that the new gap, for the first time, enables the arrester's sparkover sensitivity to be controlled independent of its arc-interrupting efficiency.

The gap-unit operates in conjunction with an improved composition of Thyrite valve disks having low resistivity and unprecedented discharge capacity.

In addition, these internal elements are sealed in super-dry atmosphere within the porcelain housing of interchangeable units. The internal gaps are shunted by highly non-linear Thyrite resistors giving self-regulating effect in controlling voltage distribution across individual gaps and across arrester-units from line to ground.

The Thyrite Magne-valve station arresters are available in ratings from 3 to 264 kv.

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* Registered trade mark of the General Electric Company.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

METAL ULTRASONIC DELAY LINES

The National Bureau of Standards recently completed an investigation of metal ultrasonic delay lines for application in electronic computers and ordnance devices. The study disclosed that use of isoelastic alloys containing combinations of iron, nickel, chromium, and other minor elements may solve one of the primary problems in this field—finding materials that yield a thermally stable delay line with respect to time delay. The investigation was conducted by R. W. Mebs, J. H. Darr, and J. D. Grimsley of the NBS thermal metallurgy laboratory.

A delay line is a device for slowing down or storing a signal in an electric circuit. At radio frequencies this can be done by transforming the electric signal into a much slower sound signal and propagating it through an appropriate medium. After a given length of time the sound signal is converted to an electric signal again. Delay lines are employed in radar, computers, and many new ordnance devices.

The use of isoelastic alloys for delay lines is apparently new, although such materials have been known and used in other applications for over 50 years. Isoelastic alloys are ones which have a constant modulus of elasticity with respect to temperature changes. Their primary use to date has been in watch springs and similar applications. Since one of the requirements for ordnance delay lines is ability to give constant signal delay regardless of temperature changes, only the isoelastic alloys and relatively few other materials can be considered for such a use.

Up to the present time quartz, mercury, water, and certain magnesium alloys have exhibited some of the qualities needed for use in ultrasonic delay lines. Quartz and mercury have been used fairly extensively in certain applications, but both have drawbacks. Quartz is expensive and hard to shape or machine while mercury is thermally unstable and is susceptible to mechanical shock, leakage, aging, and contamination. Mercury has been used, however, in the long delay lines of the National Bureau of Standards Eastern Automatic Computer (SEAC).[1] In some devices it is desirable to use a material that will transmit 10-megacycle pulses, without appreciable attenuation or distortion of the signal, and give a 50-micro-second time delay. At the same time the material must be thermally stable and be easily shaped into specific dimensions. No delay lines developed so far have all these qualities.

* Communicated by the Director.

[1] "SEAC—the National Bureau of Standards Eastern Automatic Computer," *NBS Tech.-News Bulletin*, Vol. 34, No. 9, p. 121 (September 1950).

Before the delay lines could be investigated, certain problems relating to the transducers used to transform the signal had to be solved. Quartz-crystal transducers were found to be the most efficient elements. The crystals were cut so that they transmitted only shear waves. Careful acoustical matching between delay line and crystal was required. The Bureau adopted a buffer technique for preliminary tests in which crystals were cemented to short lengths of magnesium alloy rods. A special clamp was devised to hold the unmounted ends of these buffers against the delay lines under test. In the second method for attaching crystals to delay lines, the one which was used in the final investigations, crystals were cemented directly to the delay lines as they would have to be in potential service use. Best signal characteristics were obtained using epoxy type cement and overcuring it.

Although the principal objective was to obtain a line of a length which would produce a delay of 50 microseconds, specimens of various lengths were studied. This was done to determine the attenuation per unit length and the transducer or buffer loss associated with the various materials. Delay line length varied from $\frac{1}{4}$ in. to over 6 in. The NBS study revealed that there was little effect on the transmission of ultrasound attributable to specimen cross section so long as it was not less than transducer cross section.

NBS investigated fourteen materials in the course of the work. A number of characteristics such as attentuation, distortion, and temperature response were studied for each material. The total attenuation of a high-frequency signal is the result of several factors. Besides losses in the delay line itself, there are losses due to the crystal transducer and due to the bond between the crystal and delay line. The attenuation losses of the line have been attributed to elastic hysteresis, sound scattering, and a sound diffusion process. Distortion also has several sources. It can be caused by the crystal transducer or by the matching between crystal and delay line. Internally, the principal sources of distortion are scattered signals which have been reflected or refracted back into the main beam. To investigate these effects, the laboratory made studies of the relationships between the transmission of ultrasound and such factors as chemical composition, cold deformation, annealing treatment, specimen length, and sound path cross section.

The third, and most important quality, sought in the NBS investigation was temperature stability of time delay over the range from $-50°$ to $+200°$ C. The delay time of a delay line is affected by the length and the shear modulus of the material. For most metals, the temperature coefficient of the modulus is negative and of much greater magnitude than the positive expansion coefficient. Actually, the expansion coefficient is relatively small especially for certain alloys of iron and nickel. Consequently a thermally stable delay line material must have a very small negative temperature coefficient of shear modulus.

Materials chosen for study included two magnesium alloys, a high purity and a commercial nickel, Invar, a 32 per cent nickel-iron, and 18:8 Cr-Ni steel, a 1 per cent carbon tool steel, an aluminum single crystal, and five isoelastic alloys. Of the isoelastic alloys three were of commercial origin, one was an experimental alloy, and one was a special alloy prepared in the Bureau's experimental foundry and treated in the NBS thermal metallurgy laboratory.

The electronic apparatus consisted of an RF signal generator and amplifier; pulse, marker, and delay generators; an output cathode follower; and an oscilloscope. For attenuation studies, a pulse modulated signal was fed into both the ultrasonic delay line and directly into the oscilloscope. The outputs were applied to the vertical input of the oscilloscope. As the oscilloscope deflection sensitivity and circuit constants were known, the attenuation of the delay line could be determined. For delay time studies, the marker generator provided marker pulses for the vertical input of the oscilloscope and synchronized the pulse generator output which was being applied to the delay line. The delay generator was synchronized by the pulse generator and provided in its output a delay pulse which was used to trigger the oscilloscope sweep. The sweep delay was variable over a wide range. By this method, the expanded sweep could be observed over a wide range, facilitating accurate determination of the delay time of the delay line.

For tests at elevated temperatures, a nichrome-wound alundum tube furnace was used having a uniform temperature zone over the specimen length. Thermocouples were attached to the center and both ends of the delay line. In order to obtain subzero temperatures, a very simple but effective low-temperature test chamber was constructed. It consisted of an open-top wooden box with holes drilled in its opposite ends. A thick-walled copper tube ran through the holes. The delay lines were inserted in the tube. By gradually filling the box with dry ice, the specimen was cooled slowly. The copper tube maintained effectively uniform temperatures over the specimen length.

Of the fourteen metals and alloys investigated, only two of the isoelastic alloys possessed satisfactory temperature stability over the range from $-50°$ to $+200°$ C. These materials were alloys of iron, both containing approximately 36 per cent nickel and 7 to 8 per cent chromium plus other minor constituents. While mercury and the magnesium alloy have temperature coefficients of delay time of about 300 ppm/° C. and 400 ppm/° C, respectively, one of the isoelastic materials tested had a temperature coefficient of only 8 ppm/° C. The second isoelastic alloy was nearly as good; it exhibited a constant delay time over the range from $-50°$ to $+170°$ C., with a slight increase in delay time at temperatures above 170° C.

For further technical details see "Metal Ultrasonic Delay Lines," by R. W. Mebs, J. H. Darr, and J. D. Grimsley, *J. Research NBS*, Vol. 51, No. 5 (November 1953).

DEGRADATION EFFECTS OF MUSEUM LIGHT SOURCES

Useful information regarding the deteriorating effects of modern light sources on museum specimens has resulted from a study made by Dr. D. B. Judd of the National Bureau of Standards for the New York Metropolitan Museum of Art. On the basis of NBS data on the photochemical deterioration of cellulose, the Bureau has estimated the radiation hazard for six light sources commonly employed in museums and has made similar estimates for each of these sources in combination with protective filters. The results indicate that the cool-white fluorescent lamp, when used with a suitable ultraviolet-absorbing filter, combines excellent color rendition, approaching that of daylight, with low radiation hazard.

Radiant energy from light sources gradually embrittles paper, crumbles textiles, and fades the colors of pigments and dyed fibers. This photochemical action is especially marked for sources such as fluorescent lamps which emit appreciable ultraviolet radiation in addition to visible light. However, until comparatively recently the incandescent lamp was virtually the only source of artificial light considered for museums, and the problem of radiation hazard from artificial lighting was never a serious one. Then, with the development of various kinds of fluorescent lamps, high levels of artificial light became economically feasible, and color rendition approaching that of natural daylight could also be obtained. As a result, modern museums must seek a suitable compromise between the high level of daylight-quality illumination desired by present-day viewers and a kind of lighting long accepted as involving negligible radiation hazard but yielding inferior color rendition.

The Bureau's work on this problem was largely an extension of a study conducted in 1951 for the Library of Congress to provide recommendations for the protective lighting of the Declaration of Independence and the Constitution of the United States.[1] The earlier studies, revealing that damage to documents of this kind is caused largely by ultraviolet, visible violet and visible blue radiant energy on the photochemical decomposition of low-grade paper, were utilized to set up an arbitrary scale of the *relative damaging effect* of different wavelengths from 365 to 546 millimicrons. On this basis a suitable light source and filter for the lighting of the historic documents were selected.

In the present investigation the scale of relative damage as a function of wavelength was extended to cover the wavelength range from 300 to 640 mμ. Relative damage rates above or below this range are of no interest in museum lighting because none of the sources used emit appreciable damaging energy at wavelengths outside this band. To

[1] *Protective Display Lighting of Historical Documents*, NBS Circular 538; *Preservation of the Declaration of Independence and the Constitution of the United States*, NBS Circular 505. (Both publications are available at a cost of 15 cents each from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.)

estimate the radiation hazard associated with a particular source, a *probable rate of damage per foot-candle* was computed for each of six light sources commonly used or considered for museum lighting. This quantity was obtained as the ratio of two sums:

$$\frac{\sum_{0}^{\infty} H_\lambda D_\lambda \Delta\lambda}{\sum_{0}^{\infty} H_\lambda \bar{y}_\lambda \Delta\lambda},$$

where H_λ is the spectral irradiance (areal density of radiant flux) of the light source at wavelength λ, D_λ is the relative damage factor, $\bar{y}_\lambda$ is the luminous efficiency of the source at the various wavelengths, and $\Delta\lambda$ is the interval (here 20 mμ) between the wavelengths at which H_λ, D_λ and $\bar{y}_\lambda$ are evaluated. The sum in the denominator is thus the illuminance (areal density of incident luminous flux) in footcandles.

The six sources were zenith sky, the sun, the cool-white deluxe fluorescent lamp, the warm-white deluxe fluorescent lamp, the daylight fluorescent lamp, and the incandescent lamp. The Bureau also determined the distribution of irradiance which resulted from screening each of these sources with typical filters cutting off the short-wave portion of the spectrum to various degrees.

Of the filters studied, those like Noviol 0 yielded the smallest estimates of radiation hazard. Although such filters are slightly yellowish, the small distortion in color rendition introduced by them would probably not ordinarily be objectionable. However, filters like Greenish Nultra introduce no significant color distortion and still reduce the radiation hazard almost as much. In fact, the cool-white deluxe fluorescent lamp screened with Greenish Nultra is estimated to have a radiation hazard less than that of the bare incandescent lamp, which is generally admitted to be negligible. Yet the cool-white lamp with this filter gives excellent color rendition while the bare incandescent lamp is relatively poor in this respect.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

March 17, 1954

The Stated Monthly Meeting of The Franklin Institute was held on Wednesday, March 17, 1954, in the Lecture Hall. S. Wyman Rolph, President, called the meeting to order at 8:20 P.M. Approximately 120 persons attended.

The President asked for approval of the Minutes of the January Stated Meeting, which were printed in the February JOURNAL. There being no corrections or additions, they were approved as submitted. He stated that the Minutes of the February Stated Meeting would appear in the March JOURNAL and would be submitted for approval at the next Stated Meeting.

The Secretary reported the following elections to membership for the month of February:

Active	20
Associate	36
Student	10

and a total membership, including Company and Library privileges, of 6,824 as of February 28, 1954. The President said it was gratifying to note that membership is constantly growing.

The President then welcomed the officers and members of the Philadelplia Society for Promoting Agriculture to its fourteenth Joint Meeting with the Institute. After speaking briefly of the Society, Mr. Rolph presented its President, Mr. J. Gordon Fetterman, who took the chair. Mr. Fetterman thanked Mr. Rolph for his warm welcome and expressed the appreciation of the Society. Mr. Fetterman then introduced the speaker for the evening—Dr. S. W. Fletcher, Dean Emeritus, School of Agriculture, Pennsylvania State University—and presented him with the Society's annual award for outstanding work in the science of agriculture. Dr. Fletcher's most interesting talk on "Philadelphia Leaders in Agriculture" was well received by the audience.

After a question period, the meeting adjourned at 9:20 P.M. with a rising vote of thanks to Dr. Fletcher.

HENRY B. ALLEN
Secretary

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

CAMPBELL, WILLIAM S.: Engineering Department Modernization.

ALBRECHT, H. O. AND C. E. MANDEVILLE: The Storage of Energy in Some Activated Alkali Halide Phosphors.

PAI, S. I.: On the Flow Behind Axially Symmetrical Attached Curved Shock.

MOON, PARRY AND DOMINA EBERLE SPENCER: A New Electrodynamics.

STIPPES, M. AND R. E. BECKETT: Symmetrically Loaded Circular Plates.

TAYLOR, WILLIAM C., JR.: A Neglected Method for Resolution of Polynomial Equations.

GROSS, JOSEF: Nonlinear Study of Frequency Modulated Oscillator.

KU, Y. H. AND AHMAD KAMAL: A New Homopolar Motor.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A. M. until 5 P. M. on Mondays, Tuesdays Fridays and Saturdays; 2 P. M. until 10 P. M. on Wednesdays and Thursdays.

RECENT ADDITIONS

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HARRIS, JAY C. Detergency Evaluation and Testing. 1954.
MCGREGOR, ROB ROY. Silicones and their Uses. 1954.

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AITCHISON, LESLIE AND KONDIC, VOYA. The Casting of Non-Ferrous Ingots. 1953.
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HEYN, ANTONIUS NICHOLAAS JOHANNES. Fiber Microscopy. 1954.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, MARCH 17, 1954

ACTIVE FAMILY

Kenneth E. Fry, M.D.

ACTIVE

Ernest H. Behr
John F. Currie
William E. Hendricks
William Kartin
Walter C. Koenig
Thomas H. McGuine
Frederic D. Mitchell
Hillary Robinette, Jr.
Chris Schurr
Beverley R. Scott
Joseph M. Stiteler
James Sweeten, 3rd
Leslie R. Vincent

ACTIVE NON-RESIDENT

J. W. Beams, Ph.D., Sc.D.
J. B. Johnson, Ph.D.
Robert J. Kyracou
Lewis Robert Plumb
Harold O. Woolley

NECROLOGY

Edwin H. Armstrong '41
C. Herbert Bell '36
Frederick C. Newbourg, Jr.
Edward D. Pritchett '48
N. F. S. Russell '39
H. D. Steel '42
Mrs. Benjamin Wolf '36

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, March 10, 1954)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 10, 1954.

PROFESSOR W. S. PARDOE in the Chair.

The following report was presented for final action:

No. 3271: Apparatus for Automatically Centering Metal Strips and Other Moving Objects.

This report recommended the award of a John Price Wetherill Medal to Edwin T. Lorig, of Pittsburgh, Pennsylvania, "In consideration of his invention of the Lorig-Aligner, a novel and valuable type of self-centering roll used in the rolling of steel strip and tin plate, resulting in the manufacture of a better product at a higher rate of speed and with less spoilage."

JOHN FRAZER,
Secretary to Committee

The Franklin Institute, a privately endowed institution which exists today only because of the generous benefactions of its supporters, is justly proud of the dividends in human benefits accrued from the investments made through the years by its friends. The accumulation of many bequests for general endowment and income to be used where it will do the most good, is the most important and pressing need of The Franklin Institute today.

Checks should be made payable to The Franklin Institute and sent to The Franklin Institute, 20th and The Parkway, Philadelphia 3, Pennsylvania.

Transfer of property should be made to The Franklin Institute.

A typical form is:

I hereby give and bequeath to The Franklin Institute of the State of Pennsylvania the sum of.....to be used as The Board of Managers of The Franklin Institute may think advisable for the benefit of said Institution. (For the principal and income thereof to be devoted to.....).

Additional information on gift and memorial opportunities may be obtained through the above address.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

***Abstract of* Effect of Ultra-Violet Light on Deoxyribonucleic Acid in Rat Thymocytes.**—S. J. DE COURCY, JR., J. O. ELY AND M. H. ROSS (*Nature*, **172**, 119 (1953)). The amount of deoxyribonucleic acid (DNA) recovered from rat thymocytes which had been previously irradiated with ultra-violet (UV) light was only 52.9 per cent (S. $E._{mean}$ 4.6) of the weight of that obtained from unirradiated controls.

No appreciable differences between irradiated and control samples were found with respect to relative viscosities, structural viscosities, and sedimentation rates.

The small amount of DNA recovered from irradiated tissue homogenates and the large amount of thymine present in the supernatant fluids collected during the extraction process indicate that, as a result of UV irradiation, partial fragmentation of the polymerized DNA molecule occurred.

Similarities in physico-chemical characteristics together with dissimilarities in the amount of DNA extracted suggest that not all the DNA in the irradiated homogenates was depolymerized.

NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, EXECUTIVE DIRECTOR

THE BICYCLE COLLECTION

Few adults of this sophisticated era of speed and luxury can look upon the bicycle as a means of locomotion without an indulgent smile. However, the bicycle deserves more respect. Certainly, those who use an automobile have reason to think kindly of the bicycle because it bequeathed some of those things to the motor car which make for comfort and efficiency.

Like most machines, the bicycle was developed to conserve human energy. Its origin, like that of the flying machine, may have existed in men's minds long before it became practical. In the church at Stoke Pogis in England (memorable through Gray's *Elegy*) is a window picturing a celestial trumpeter trundling a velocipede over a cloud bank. This window dates back to the year 1642, two hundred years almost before Charles, Baron von Drais invented the velocipede to ease the labor of trudging through the state forests of Bavaria where he was inspector.

The Draisine was propelled by vigorously working the legs to provide leverage while the rider remained seated. The machine was invented in 1816, and the Museum is fortunate to possess an example which was made only a year or two later.

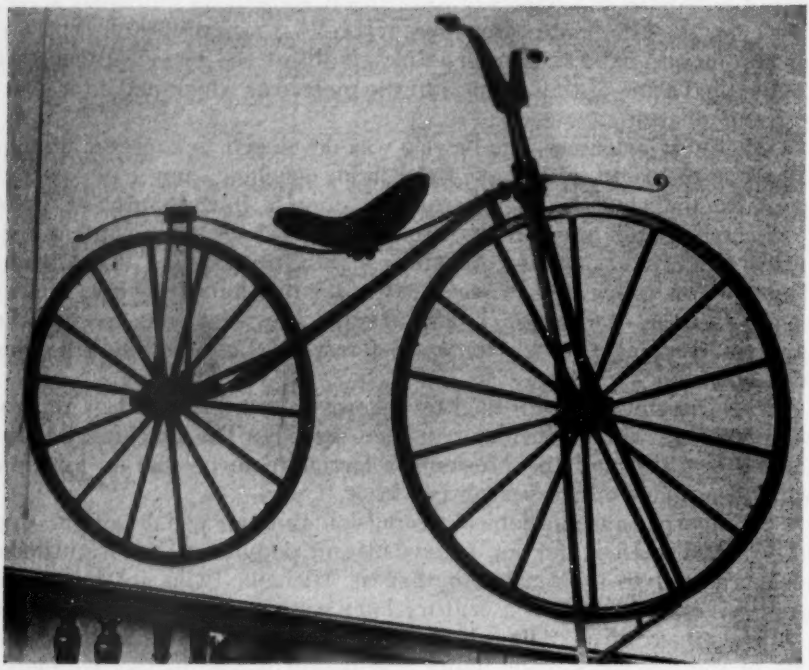
Strange to say, mechanical propulsion through pedals, originating in Scotland in 1839, did not achieve instant popularity. Not until the idea occurred to a Frenchman, Ernest Michaux (who got it from a grindstone), a quarter of a century later were pedal propelled bicycles made commercially. The first American patent was filed in 1866, and one of the machines made under this patent is also in the Museum's collection.

Observe how rapidly progress was made. At a Bicycle Show held in Paris in 1869, we get a foresight of those features which were to assist the automobile engineer in his task. One of the exhibits is described as producing two revolutions of the wheels for every one of the pedals for cycling on level ground, but a gear reduced this to one revolution when a hill had to be climbed. Another boasts a four speed gear and mudguards. A third had "independent pedals," which meant that this was the introduction of free-wheeling.

Within a year or two these annual shows were featuring bicycles with ball-bearings to reduce the fatigue of pedalling. Ball-bearings were received with widespread appreciation and were promptly applied to innumerable mechanical applications for the purpose of reducing fric-

tion. The pneumatic tire, originating in Ireland, was a valuable contribution to comfort and also served to draw attention to the necessity for better road surfaces if transportation over them was to develop.

Thus, the preliminary work performed upon the bicycle spared the automobile engineer from having to invent some of the features that were essentials on the motor car. Perhaps this may encourage visitors to look upon the old (and new) bicycles in the Museum collection with more respect.



The Draisine, invented by Charles, Baron von Drais, in 1816. This specimen in The Franklin Institute collection was made a year later and has a solid iron frame, an improvement over the wooden frame of the original.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

COMBUSTION STUDIES: CARBON DISULFIDE-OXYGEN EXPLOSIONS

BY

ALBERT L. MYERSON

Practically all the energy the human race requires for transportation, heat, light and other essential functions of its present civilization is obtained through the process known as combustion. Notable exceptions include hydroelectric power and, for the future, nuclear and solar energy. Now it is quite apparent that coal and oil can be burned for heat, gasoline exploded in internal combustion engines, and jet and rocket fuels successfully ignited, without our understanding the precise nature of the chemical process whereby the energy is released. But, for instance, if research in the combustion (and refining) of gasoline hydrocarbons had not proceeded from the time at which the first Ford was built, it is apparent that the development of the automobile would not have continued at a rate even approaching that which it has. Similarly it is most important that we understand the chemical mechanism of the propelling reactions of jets, rockets, and guns, if we are to improve their efficiency and increase their ranges.

In addition to the role of combustion in converting fuels to energy, new chemical processes are being considered which employ partial combustion in synthesizing new molecules.

The Section for Chemical Kinetics and Spectroscopy at The Franklin Institute Laboratories has devoted a large portion of its research to combustion processes of various types. Many of the projects are concerned with ordnance and sponsored by Government Agencies. Among those sponsored by the Armed Forces has been a study of the chemical mechanism of the oxidation (combustion by oxygen) of carbon disulfide (CS_2).[1] Although the latter is not used as a fuel, jet or otherwise, it is theoretically of very high efficiency and the techniques and theory involved in the study of the mechanism are quite relevant to many important fuels.

The initial work[2, 3] on this program consisted of a study of ignition limits (also called explosion limits or boundaries) of mixtures of CS_2

[1] Sponsored by Wright Air Development Center, Dayton, Ohio.

[2] Presented at 123rd Meeting of the American Chemical Society at Los Angeles, Cal., March, 1953.

[3] A. L. MYERSON AND F. R. TAYLOR, "The Ignition Limits of 1–3 Mixtures of Carbon Disulfide and Oxygen," *J. Am. Chem. Soc.*, Vol. 75, p. 4348 (1953).

and oxygen (O_2). An ignition limit defines the conditions of temperature and pressure at which a given mixture of gases will explode. It is also necessary to specify the volume of the container and, in this case and others of the so-called chain-branching type, the condition of the surface of the container. Determinations of boundaries of this type have both practical and theoretical implications. If one were concerned with these mixtures, as a fuel or otherwise, it could be important to know under what conditions explosion might or might not take place. For purposes of basic knowledge the shape of the boundary curves is invaluable in interpreting the chemical mechanism. It is in terms of the latter aspects that this work will be briefly discussed.

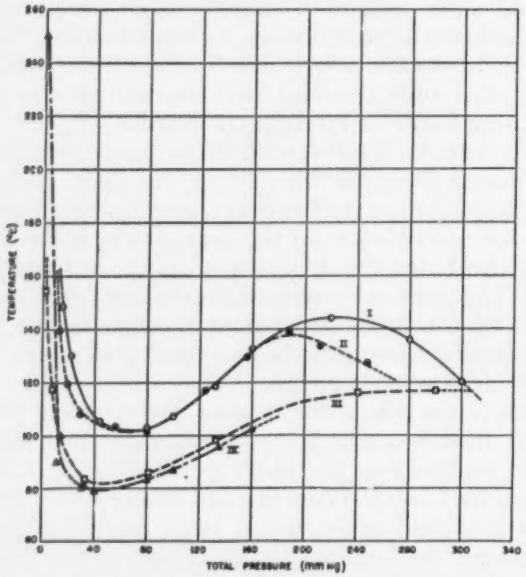


FIG. 1. Ignition limits of $CS_2 + 3\ O_2$ as a function of total pressure and temperature.

A set of boundary curves which specifies the region of explosion (all the area above the respective curve) for *definitely restricted conditions* is shown in Fig. 1. These curves hold only for the conditions of temperature, pressure, mixture ratio, flask size, shape, and surface, and even method of mixing, under which the experiments were performed. In order to understand how boundaries of this shape arise, it is necessary to consider more intimately the nature of the chemical reactions occurring. All evidence points to the fact that explosions of this type are brought about by the rapid propagation of very active chemical species arising from the reacting molecules, and known variously as free radicals, active centers, or chain carriers. When conditions, as mentioned, are

appropriate, a few (that is, thousands) of these active centers are formed from some interaction of the normal molecules, perhaps in the gas phase or catalyzed on the vessel wall. One active center, by reaction with a molecule of the normal reactant (for example, CS_2) will yield one or more active centers. Each of these latter will react with molecules of the other reactant (O_2) to provide one or more active centers capable of reacting with CS_2 again. If, in either step, more than one chain carrier is provided from one, chain branching and explosion result. This process may, of course, be more accurately and completely described through mathematical and chemical equations.

It will be noted, from Fig. 1, that with initial increase of the pressure from zero, the temperature boundary drops (first limit), indicating that increasing gas density is facilitating explosion. It can be shown that this is caused by the decreasing rate of diffusion of the active centers at higher pressures. They are thus prevented from reaching the vessel walls at which their usefulness as chain carriers is lost with certain probability characteristic of the wall and the molecule. As the pressure increases further, it can be seen that the boundary rises (second limit) or that explosion is now being inhibited. The inhibition can only be ascribed to loss of active centers in three-body collisions. This is deduced from the fact that the ratio of three-body to two-body collisions increases with pressure and seems to be the only effect of higher pressure in this pressure range that is unfavorable to more rapid kinetics. An effectively inert third body, present during a collision which would, without the third body, result in more active centers, can prevent propagation. It accomplishes this by carrying off the energy of reaction which would otherwise be involved in decomposition of the reaction complex. Thus, if A and B are active centers and AB, B_2, AB_2, and M more stable species, then these two alternatives exist:

$$A + B_2 \rightarrow AB + B \text{ (propagation)}$$
$$A + B_2 + M \rightarrow AB_2 + M^* \text{ (chain breaking)}$$

where M^* is in an excited state.

The reasons for the third boundary are not quite as certain, and in this case it must be pointed out that this limit is distinctly peculiar to the particular method employed in mixing the gases. The latter process was carried out by allowing O_2 at room temperature to flow quickly into the CS_2 at equilibrium in a thermostatted vessel. In general, the third limit here may be due to one of several causes. These are (1) processes which regenerate chain carriers, (2) increasing importance of thermal explosion (balancing of heat evolution and release) or (3) some experimental phenomenon which is causing ignition at temperatures below what might be considered to be the theoretical ignition limit in this region. With reference to (3) there is probably no experimental method possible for mixing and heating a desired gaseous combination in a

matter of milliseconds. However, other methods, such as one recently adopted in continuing this research, may be more meaningful from a kinetic point of view.

The study of these ignition limits has now been extended to the effect of varying composition, addition of significant foreign gases, and coatings and other variables. However, a major and probably more significant part of this program has employed absorption spectroscopy to the study of these explosions. The experimental details have been released for publication,[4] but the chemical aspects are still under investigation.

[4] P. L. HANST AND A. L. MYERSON, "Absorption Spectroscopy of Explosions," *Rev. Sci. Instruments* (forthcoming).

BOOK REVIEWS

METHODS OF THEORETICAL PHYSICS, by Philip M. Morse and Herman Feshbach. Parts I and II (two volumes), 2038 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $30.00 (set).

Even without reading the authors' preface to this two-volume treatise it is quite easy to see that their main purpose has been to present a unified treatment of the mathematical tools which have been found most useful in the "field-theory approach" to physics. In this reviewer's opinion Professors Morse and Feshbach have more than accomplished this purpose; they have put into "closed form" the main analytical tools of present-day physical theory, and they have done so with a style which is exceptionally elegant and readable. The book is ideally suited for what used to be called "self-study."

The first volume contains eight chapters. Chapter 1 represents a unified introduction to the concept of a field, and gives an introduction to vector and tensor analysis including an unusually interesting treatment of spinors, four-vectors and the Lorentz transformation. Chapter 2 is the central core of the complete work, for in this chapter are given the methods of formulating a large number of the most important partial differential equations of physics, and it is of course these equations which describe in highly abbreviated form the general laws of Nature as well as they are understood today. From this point of view the remainder of the first volume and all of the second volume can be considered the detailed mathematical study and interpretation of these basic equations.

It has been observed that many of the universal laws can be formulated in terms of a tendency to make "something" as large or as small as possible—a tendency toward an "extremum." This tendency, more properly called the Variational Principle, is discussed in Chapter 3; here arise the problems of energy density and energy flow associated with fields, the Hamiltonian function of a system, (canonical) transformations which preserve the form of the Hamilton equations, energy in elastic media and in electromagnetic fields, the impedance concept, momentum density associated with fields, and gauge transformations of potential in an electromagnetic field.

Chapter 4 is a "short course" (about 120 pages) in the theory of functions of a complex variable, including the related transforms of Fourier, Laplace and Mellin, conformal mapping, the calculus of residues, and certain special functions.

Chapters 5 and 6 deal with Ordinary Differential Equations and with Boundary Conditions and Eigenfunctions, respectively. These two chapters, as a circus barker would put it, are alone worth the price of the book! Chapter 5 discusses the classification of differential equations according to the number and the nature of their singular points, together with a very useful treatment of integral representations of solutions. Chapter 6 gives a classification of boundary conditions and the nature of eigenfunctions; the superposition of these eigenfunctions to give general solutions and the relation to abstract vector space; the way in which the parameter in the Liouville equation affects the general behavior of the solution (Sturm-Liouville problem), completeness, asymptotic formulas, self-adjoint and Hermitian operators and eigenvectors.

Chapter 7 is concerned with Green's Functions, and includes applications to electrostatics, optics, transient motion of a circular membrance, Klein-Gordon differential equation, diffusion, and heat transmission. The chapter closes with the representation of the theory of Green's function in terms of vector space and vector operators.

Chapter 8 treats the subject of Integral Equations, their classification, relation with boundary conditions, Fredholm and Volterra equations. The general properties of integral equations are considered, with a detailed study of various types of kernels; solutions of integral equations; relation to Fourier integrals.

The second volume contains five chapters

and represents the theoretical physicist's "box of tools." Chapter 9 is on Approximate Methods, and discusses Perturbation Methods, Boundary Perturbations, Perturbation Methods for Scattering and Diffraction, Variational Methods and a Tabulation of Approximate Methods. Numerous examples of these methods are worked out in the text.

The remainder of the book, Chapters 10 through 13, come under the heading of "How to Solve Difficult Problems in Physics." Chapter 10 shows how problems are attacked when they involve the Laplace or Poisson Equations. Chapter 11 deals with problems involving the Wave Equation. Chapter 12 discusses problems in Diffusion and problems in the Schroedinger Wave Equation, including at least as much of the mathematical aspects of wave mechanics as is usually given in first-year graduate courses on the subject. The final chapter in the book, Chapter 13, is on Vector Fields.

The book contains over 300 problems, and each chapter ends with a summary of the "high points" in that chapter, together with a brief bibliography. A novel feature of the book is that a number of stereoscopic figures are included; however, this feature contributes little if anything to the already excellent quality of the book. There is an extensive Index (the same in each volume), a Glossary of Symbols Used, a Bibliography of Tables of Functions, and seventeen tables of numerical values of common and quasi-common functions.

Physicists will be indebted to Professors Morse and Feshbach for many years to come, for writing a book which is certain to play an important part in the training of physicists, both present and future!

C. A. DOMENICALI

THEORY OF METALS, by A. H. Wilson. Second edition, 346 pages, diagrams, 19 × 27 cm. New York, Cambridge University Press, 1953. Price, $8.50.

It is a pleasure to report that Mr. Wilson's *Theory of Metals* is again available. The first edition, published in 1936, has remained a valuable text and reference work in spite of the many advances which have been made in the theory of metals in the last seventeen years. Those familiar with the earlier work will need to know only that the second edition is extensively revised and enlarged.

The second edition follows the same general outline as the first, beginning with an account of the early Drude, Lorentz, and Sommerfeld theories of conduction. The second chapter discusses the motion of an electron in a perfect crystal lattice. Two chapters are devoted to the structure of metals and alloys and to the effects of this structure on the energy spectra of the outer electrons of the atoms composing the lattice. Semiconductors are discussed in Chapter V. The theoretical description of electronic processes in these materials is somewhat simpler and agreement between theory and experiment more exact than is the case for metals. Thermal and magnetic properties of metals are treated in Chapter VI. Mr. Wilson has made many contributions to the theory of the diamagnetism of conduction electrons. His treatment of this topic is excellent. The discussion of ferromagnetism in Chapter VII is based on the collective electron model of Block and Stoner. The consequence of the alternate, Heitler-London type approach, is not explored. In the last three chapters various transport phenomena are discussed. First the formal theory of electrical and thermal conduction is presented. Thermomagnetic, galvanomagnetic and thermomagnetic effects are defined and comparison made between theoretical expressions and experimental results.

Under the heading "Mechanism of Conduction," such topics as coupling between electrons and lattice vibrations, residual resistance and lattice steady state are discussed. In the final chapter, the transport equation is set up as a variational problem, which is the form best suited for calculating higher order corrections. The principal formulae of the previous two chapters are rederived using the variational method.

There is an appendix on the Fermi-Dirac statistics. Omitted from the second edition are the chapters on super conductivity, on optical phenomena, and the appendix on surface phenomena. As the author explains in his preface, the space saved by their omission has permitted a fuller exposition of those topics constituting the main theme of the book.

Throughout the book theoretical expressions are developed in an orderly, compact manner. Numerical comparisons with experimental data are made where possible. Inadequacies in the theory are clearly in-

dicated and possible avenues for further theoretical development given. Mr. Wilson's prose style is always clear and lucid but the vast mass of necessary mathematical detail demand the close attention of the reader. The results are well worth the effort.

In this age of increasing costs the publishers are to be congratulated for bringing out the edition in a new larger format at the same per word price as in 1936.

F. J. DONAHOE

PASTEUR'S AND TYNDALL'S STUDIES OF SPONTANEOUS GENERATION, edited by James Bryant Conant. Harvard Case Histories in Experimental Science, No. 7. 61 pages, 15 × 23 cm. Cambridge, Harvard University Press, 1953. Price, $1.25 (paper).

The series of "Harvard Case Histories in Experimental Science" is primarily designed for students who are majoring in the humanities but who seek an understanding of science. However, it deserves a wider public. The science student is accustomed to have the work of earlier scholars presented to him in such simple fashion that he is prone to imagine the problems they faced were so easy of solution that he could have solved them himself. Insufficient attention is given to the contemporary state of knowledge and the apparatus available. No discovery in science can be correctly appraised without a knowledge of the discoverer's approach and his methods of attack.

This excellent series of little books furnishes an admirable introduction to experimental science. It is commended to any scientist who has to explore a field outside his own speciality, but the layman will most appreciate it since it offers an understanding of science without the tedium of having to memorize factual information.

The latest addition to the series deals with the problem of spontaneous combustion of living organisms from inert matter. Early in his researches into the biological process known as fermentation, Pasteur formed the hypothesis that the process of fermentation is not associated with death and decay, but was a growth of living organisms. In carefully selected extracts from Pasteur's "Memoir" to the French Academy of Science, the history of the subject is outlined and an account given of the essential features of the experiments with proved the truth of his hypothesis. Editorial notes add considerably to the understanding of the presentation.

The most prominent adherent of Pasteur was the eminent English surgeon Joseph Lister, who stimulated John Tyndall to make further investigations into the subject, by which some baffling contradictions were cleared up. The essential features of Tyndall's article are here reproduced and the way is made clear for the adoption of the bacteriological procedure of sterilizing at temperatures above the boiling point of water.

We can but repeat what has been said of the six other booklets in the series: that we know of no better introduction to science than through these well edited accounts of great achievements.

T. C.

CHROMATOGRAPHY, by Edgar Lederer and Michael Lederer. 460 pages, diagrams, 16 × 23 cm. Houston, Elsevier Press, 1953. Price, $9.25.

Reference to chromatography was first made by Tswett in 1903. Much later, in 1931, Kuhn and Lederer realized the possibilities of Tswett's method. Now contributions to this field number in the thousands. Last year's Nobel Award to Martin and Synge for their work in this and related techniques is ample evidence of its importance.

The text is divided into five parts: Adsorption Chromatography, Ion Exchange Chromatography, Partition Chromatography, Chromatography of Organic Substances and Chromatography of Inorganic Substances. Most of the practical and useful information relating to R_f values in various solvents is collected in tables. The bibliography is the most complete of the last 13 years, consisting of 1879 references. A subject and author index is also provided.

The first three divisions of the book are devoted to fundamental principles, apparatus and techniques. The authors have distinguished between three types of chromatography in each of these divisions, however, this distinction is arbitrary and it is often not certain which of these phenomena is operating in a given separation. Each of these three divisions begins with a general discussion of principles involved in that particular definition of chomatography. The general

discussion is then enlarged upon in the following sections, which may contain tables, illustrations, mathematical calculations, allied methods, apparatus involved or variations of apparatus. Such modern development as tracer techniques is given consideration.

The fourth division is by far the most extensive, since organic chemistry and biochemistry first gave rise to the technique. It discusses such a wide variation as hydrocarbons; alcohols and phenols; aldehydes and ketones; acids; nitrogen, halogen and sulfur compounds; phosphoric esters; synthetic dye stuffs; carbohydrates, lipids and amino acids; peptides; proteins; purines, pyrimidines and related compounds; natural pigments; vitamins; hormones; antibiotics and separation of sterioisomers. Each one of the former subjects is accompanied by the known R_f values and authors responsible for the data, some explanation of the effects of functional groups on the process wherever the literature has made it possible and certain pertinent illustrations.

The last division is the first comprehensive treatment of inorganic chromatography. It considers the separation of the metals into groups, separation of anions and cations, separation of acids and other more specific separations. Consideration is given to the separations within a group such as: alkali metals, alkaline earths, rare earths, transuranic elements, platinum metals and transition metals.

In many respects, chromatography is a cookbook practice. Too few have been interested in the mechanism of the process or in a detailed investigation of these curious and bewildering phenomena. The authors have been aware of this and attempted some explanation whenever possible.

PHYLLIS A. PARKIN

STABILITY THEORY OF DIFFERENTIAL EQUATIONS, by Richard Bellman. 166 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $5.50.

The stability theory of differential equations is concerned with the problem of determining the properties of the solutions of differential equations, the stability of the solutions and their asymptotic behavior, rather than determining explicit solutions. These properties of the solutions are deduced from the analytic form of the differential equations. In most cases this is a far simpler problem than the determination of explicit solutions, and in a great many physical problems the solution of this simpler problem is all that is required. This subject has become very important in the analysis of mechanical and electromechanical systems, especially those with feed back. These systems are of common occurrence in the fields of computers and automatic controls.

The book under review is intended as an introductory textbook to stability for graduate students in mathematics. However, despite the fact that it is an introduction to the stability problem, it contains a large collection of results which should be useful to workers in fields where the problem of stability of systems arises. Even when the specific results required are not contained in this book, the book serves as a valuable introduction to the extensive literature on the subject. The level of the book is fairly elementary in that advanced analytic and topological arguments are avoided.

Vector and matrix notation is used throughout the book. Hence the first chapter discusses all the results in matrix theory that are required for the later development. This chapter is also concerned with various results in linear differential systems. The second chapter discusses the concept of stability and the problem of determining the asymptotic behavior of solutions of equations with nearly constant coefficients. Existence theorems for nonlinear systems are taken up in Chapter Three. The fundamental results of Poincaré and Liapounoff concerning stability of solutions of nonlinear systems is dealt with in Chapter Four. Chapters Five and Seven are concerned with the asymptotic behavior of the solutions of several specific types of nonlinear differential equations, while Chapter Six deals with the second-order linear differential equations.

There are many exercises which are intended to extend the results given in the text. There is also an extensive list of references. These are listed by section for each section in the book. This makes it an easy matter to find the literature for each special topic.

H. L. PLATZER

ANNUAL REVIEW OF NUCLEAR SCIENCE, VOLUME 3, edited by James G. Beckerley. 412 pages, 16 × 23 cm. Stanford, Annual Reviews, Inc., 1953. Price, $7.00.

This is the third volume in this series of very useful review publications. The scope has been broadened to include radiation chemistry and radiation biology in addition to nuclear physics. These added subjects are concerned with the interaction of nuclear radiation with chemical and biological materials and with chemical techniques. This broadening is certainly in keeping with the breadth indicated by the nuclear science title. However, while these new topics may be very interesting, it is questionable whether those workers interested in one field of nuclear science will have much need or desire for information in the other fields.

Of the fifteen chapters, six can be considered as being on nuclear physics, four as on radiation chemistry and five on radiation biology. These include some useful reviews on techniques: neutron measurements, photographic emulsion techniques, radiochemical separation methods, and dosimetry and protection. The nuclear physics reviews cover such topics as mesons, cosmic rays, neutron optics, and electron and gamma ray interaction with nuclei. The nuclear chemistry reviews include articles on radiation chemistry, chemical effects of nuclear transformations and isotope effects in chemical reactions. Those in the biological field include verterate radiobiology, cellular radiobiology and radiation injury in humans.

There must always be a compromise in review articles, a compromise dictated by space limitations. The editors state that fundamentals cannot be covered. That such is not the case is seen in several of the articles, notably the excellent surveys on neutron optics and radiation chemistry. Perhaps the editors would be wise to modify their viewpoint so as to allow inclusion of fundamentals in the first survey of a given topic. Any other plan merely decreases the effectiveness in the communication of knowledge to the non-specialist.

Some of the reviews cover as little as one year, some cover the field from its birth. Most of the articles are well written and have a sufficiently broad approach to render meaningful the references to recent literature. However, the article on isotope effects runs counter to the generally excellent level. It is quite short and merely abstracts the literature for the past year. There is no introduction and there is no correlation between the results of the various workers. It would be better to reduce the number of chapters and give each more space than to include a great many low level chapters.

The chapter on radiation injury is certainly one of the most vivid articles. Case histories of humans injured in various ways are given and a reading of this chapter should make the average laboratory researcher more careful.

There is an impressive editorial board and an equally impressive list of 22 authors. The surveys were concluded early in 1953 except for the cosmic ray article which includes a six page summary of the Bagnéres Congress held in July 1953. The subject and author indexes cover all chapters.

This book and others of the same character provide one of the easiest ways for a non-specialist to keep up to date in the field of nuclear science. LEONARD MULDAWER

PRACTICAL CHROMATOGRAPHY, by R. C. Brimley and R. C. Barrett. 128 pages, diagrams, plates, 14 × 22 cm. New York, Reinhold Publishing Corp., 1953. Price, $5.00.

This little book is essentially a how-to-do-it manual, as one would gather from the title. It serves as a useful introduction to the experimental techniques involved in the various chromatographic methods. This very powerful separation method now appears to be permanently mislabled; in most methods which are today classed as chromatographic, color plays no role.

The term as now used covers those methods in which a mixture of two or more components is separated by the successive partition of the components between a moving phase and a stationary phase. These authors divide their subject into two parts: paper chromatography and column chromatography. The latter is subdivided into absorption, partition and ion-exchange methods. The term partition is applied when use is made of the partition by solubility of the components to be separated (solutes) between two immiscible phases. If the fixed phase holds the solutes by absorption this term is used. Ion

exchange chromatography makes use of acidic or basic resins to separate ionic substances. Ion exchange has of course found a number of applications outside the laboratory.

In the short space of this book the authors can do little more than describe the methods and give examples, which in some cases are described in considerable detail. Theoretical discussion of the various methods is kept to a bare minimum. A much fuller treatment of some parts of the subject would have been desirable. For instance the classic rare-earth separation by ion exchange is hardly more than mentioned.

A final chapter is devoted to accessory apparatus such as automatic fraction collectors (to allow the experimenter to go out for lunch). An Appendix A gives more details on selected separations. A bibliography of 113 references is included as well as an index.

E. R. STEPHENS

ELECTRICITY & MAGNETISM, by Edson Ruther Peck. 476 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1953. Price, $7.50.

Professor Peck of Northwestern University's Physics Department has written a new textbook on electricity and magnetism. It is clearly for teaching purposes in the instruction of physics and electrical engineering majors at the undergraduate level.

About all that can be accomplished by the writing of a new book of this general type is the revision of teaching material in the attempt to make its presentation more effective. Some improvement can be realized through modernizing and bringing the material up to date, but in a book on first principles there is very little obsolescence, for here most of our scientific advances are made in the realm of detailed concepts or applications.

Much of the elegance of the formal mathematical treatment of electrical theory is missed during the student's brief exposure to the prescribed courses. On the other hand, a full working knowledge of this material can be a great source of satisfaction and may also mark the difference between the dull, handbook engineer and the more diversified theorist. Whatever can be done, therefore, to leave in the minds of the students a better understanding of dielectric theory, the magnetic properties of matter, and other basic concepts is valuable. The text works diligently to this end.

Professor Peck apparently believes that the solution of problems which are rather easy and can be solved directly from relations given in the text are the best form of exercise for the student. Certainly there is often much bewilderment resulting from so called "challenging" problems and extended derivations. Here the result depends to a large extent upon the enthusiasm and tenacity of the individual student who may or may not rise to the occasion. It would seem better in general to carefully show the way and to omit as far as possible those explanations which are "left as an exercise for the student." This view appears to be shared by Professor Peck.

The one exception to clarity and simplicity comes at the end of the book. Here the author felt it necessary to make some mention of electromagnetic waves before ending the course. He therefore undertook a brief introduction to radiation and electromagnetic wave motion, i.e., Maxwell's Equations. This ambitious undertaking in the final pages of the book cannot serve more than to arouse the student's curiosity or dismay him. The treatment in this brief section is considerably more advanced than that of any previous part of the volume and may by comparison prove to be a somewhat indigestible dessert for the average scholar as he reaches the end of the book.

C. W. HARGENS

STRESS CONCENTRATION DESIGN FACTORS, by R. E. Peterson. 155 pages, charts, 24 × 29 cm. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1953. Price, $8.50.

The significance of proper detail design is becoming more and more recognized as an important factor in successful engineering design. In fact, it is often the small details which make or break the over-all design, be it an automobile, a trailer, a railcar or a piece of artillery. And the concept that is frequently overlooked is the free and uninterrupted flow of stress (or strain) from one part to another during the repeated application of load (fatigue). Sharp corners and abrupt changes in section are the usual details which cause concentrations of stress.

It is not uncommon to make a structure or casting stronger by making it lighter, because in the redesign the stress raisers have been eliminated by removing unnecessary ribs or reducing the thickness of unnecessarily thick plates.

Much experimental knowledge of the phenomenon of stress concentration in various details of design has been gained in recent years. Mr. Peterson, Manager of the Mechanics Department of Westinghouse Research Laboratories, with his assistants has assembled a large portion of these data in the form of charts and graphs for quick and easy reference in *Stress Concentration Design Factors*.

This book—or, more properly, design manual—is a handbook for stress concentration in such design details as grooves and notches, shoulder fillets, holes in plates and shafts, and such miscellaneous elements as keyways, gear teeth, crane hooks and helical springs. Except for an introductory chapter on definitions and design relations and short introductions to each section, there is no text; the book consists primarily of approximately one hundred charts of stress concentration factors for the various design elements mentioned above. Since the material is common to all machine design, any structural engineer or designer will find the book invaluable. Some of the data, no doubt, have been published before; but here they are assembled under one cover for ready reference. The book should prove very useful.

E. W. HAMMER

THE ATOMISATION OF LIQUID FUELS, by E. Giffen and A. Muraszew. 246 pages, plates, diagrams, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1953. Price, $6.00.

The processes involved in the atomization of liquid fuels have been studied for some time. This has been necessary since atomized liquid fuels are used in the gasoline and Diesel engine, steam power generating furnaces, and in the ordinary home oil burner. More recently the advent of the gas turbine and the jet engine has intensified the need for knowledge of this subject.

The authors have, in the past, contributed a number of technical papers to this field, most of which were sponsored by the Motor Industry Research Association of Great Britain. Their papers have contained valuable material. Their book, however, marks a milestone in the field of liquid atomization; it is the first to offer a comprehensive treatment of the subject. Previously, the worker in this field had recourse only to a search of technical papers or to the relatively meager information tucked away in texts on internal combustion engines and steam power generation. Now this book is available which covers every aspect of liquid atomization.

The authors open their discussion by treating the disintegration of liquid jets and droplets. They summarize the early work of Lord Rayleigh on the stability of a jet subject only to the influence of surface tension. They then progress to the modern theories of Haenlein, Weber, Castleman and others.

The main body of the book is devoted to fuel spray characteristics and the effect of various parameters on these characteristics. The effect of the atomizer, liquid properties, injection pressure, and the properties of the surrounding gaseous medium are considered. Short chapters on the swirl atomizer and the application of dimensional analysis to the study of atomization are included. The authors round out their book with a complete account of the experimental methods used for the measurement of spray characteristics and droplet size. A list of references to the best known works on atomization and allied subjects is given.

A great deal of information has been packed into this book of little more than two-hundred pages. It will become a valuable tool for those concerned with the atomization of liquid fuels. M. P. NORIN

PROCEEDINGS OF THE WESTERN COMPUTER CONFERENCE. 231 pages, illustrations, 22 × 28 cm. New York, Institute of Radio Engineers, 1953. Price $3.50 (paper).

These *Proceedings* consist of a series of papers presented at the Western Computer Conference sponsored by the Joint IRE-AIEE-ACM Computer Conference Committee. There are nineteen papers which deal with specific technical subjects in the computer field. In addition, there is a report of a panel discussion on the evaluation of analog and digital computers. For completeness of

coverage, even the keynote and luncheon addresses are included.

In the panel discussion, the ever-present question of digital *versus* analog computers was debated. Dr. Louis Ridenour stated that it makes very little sense to debate the comparative merits of the two techniques because the practical information machines of the future will involve an intimate mixture of both. Based on his limited experience, this reviewer believes that this is a very important point and should be considered by the engineers and scientists in the field.

The contents of the *Proceedings* can best be conveyed by listing the subject matter of the four technical sessions: Session I, commercial applications; Session II, computer solution of dynamical problems; Session III, digital computer components; and Session IV, various topics on analog and digital components.

There is an obvious value in the *Proceedings* to people who are working in one of the fields covered by the technical sessions—memory elements, computer solution of dynamical problems, autopilot design, etc. For the most part, these papers describe improvements or advances in techniques discussed at previous meetings.

Of more general interest are the papers included in Session I; this is particularly true of a paper on Automatic Data Processing in Larger Manufacturing Plants. The subject involves more than just automatic accounting machinery. The authors describe in block diagram form a proposed production control system for a large job shop. There is an opportunity here for the electronic engineer to develop the "blocks" in the block diagram.

IRVING GLASSMAN

AN INTRODUCTION TO THE THEORY OF SEISMOLOGY, by K. E. Bullen. Second edition, 296 pages, 14 × 22 cm. New York, Cambridge University Press, 1954. Price, $6.50.

In a highly technical and authoritative book K. E. Bullen, Professor of Applied Mathematics in the University of Sydney, sets down the principles on which modern seismology is based. This is the second edition of the original book published in 1947. The vigorous activity in seismology gave impetus to the revising and rewriting of this work.

While the author states: "In the interests of terseness, much use is made of cartesian tensors and the summation convention; it is not necessary for the reader to have previous knowledge of tensors, since very little actual tensor theory is used beyond what is needed for an understanding of the stress and strain tensors and the text supplies what is necessary for this purpose." To this reviewer these remarks constitute an understatement of no mean magnitude.

A thorough mathematical background is necessary to stay with Dr. Bullen in this work and only those who are specialists in the discipline can do so.

An Introduction to the Theory of Seismology is divided into 15 chapters with the first chapter a brief introduction setting forth the aim of the book.

Chapters II and III are concerned with the mathematical theories of elasticity and waves. The next five chapters contain the application of the wave theory to the problem of wave motion in an elastic body.

In chapters IX through XI the principles of the seismograph, the treatment of instrumental data and the organization of the seismological stations are described.

Chapters XII and XIII show how geophysicists apply the seismological principles and lessons to the determination of the properties of the earth's interior.

Chapter XIV discusses the questions which arise at the focus of an earthquake. Here is detailed a discussion of the energy released in an earthquake, the distribution of earthquakes and the frequency of aftershocks.

The final chapter is a catch-all where topics like microseisms, artificially induced earthquakes, quake resisting structures etc. are reviewed.

This book is for the specialist.

I. M. LEVITT

PRINCIPLES OF COLOR PHOTOGRAPHY, by Ralph M. Evans, W. T. Hanson, Jr., and W. Lyle Brewer. 709 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1953. Price, $11.00.

Never before has there been assembled in a single text such a wealth of the material necessary for an understanding of the state of the art of color reproduction. Basic principles, instrumentation, materials, and proc-

esses are discussed clearly, and in adequate detail. In addition, a particularly comprehensive bibliography is appended. Mathematical developments are included wherever they contribute to the rigor of the exposition, but the text is so worded that the principles involved and the conclusions reached may be understood without a detailed study of the equations.

This text should be particularly valuable to engineers working with color reproduction processes, including color television engineers. It will not enable the casual Kodachrome photographer to improve his product markedly after an hour or two of reading, but the serious color photographer will find a study of this text both rewarding and enjoyable.

The chapters on visual processes and responses are particularly interesting, and point the way to one of the conclusions that the authors have reached: that because of the complexities of the interrelations among the variables, color photographic processes must be developed empirically. On the other hand, the authors point out that because of better insight into the contributions of many of these variables, and because of the development of the theory, investigations that would have been meaningless a few years back may now be undertaken and interpreted.

L. P. TABOR

THE AIM AND STRUCTURE OF PHYSICAL THEORY, by Pierre Duhem, translated by Philip P. Wiener. 344 pages, 16 × 24 cm. Princeton, Princeton University Press, 1954. Price, $6.00.

"La théorie physique: son objet, sa structure" was published in 1906. Its second, unchanged edition (1914), supplemented by the articles "Physique de croyant" and "La valuer de la théorie physique" provides the basis for the present, first, English translation of this excellent work.

Written nearly half a century ago, on the threshold of the revolutionary development of quantum physics, it cannot but bear some marks of its age. Yet, most results of the author's penetrating analysis of the motivation and internal structure of physical theories retain their validity in the present, changed, setting.

Part I deals with the philosophical (or, better perhaps, psychological) motives underlying the historical development of the physical theories. Its scope is indicated by the chapter headings: I. Physical Theory and Metaphysical Explanations; II. Physical Theory and Natural Classification; III. Representative Theories and History of Physics; IV. Abstract Theories and Mechanical Models. In the first chapter, the author demonstrates that "no metaphysical system suffices in constructing a physical theory"; in the second, he defends the view that a theory provides a concise classification of observable physical facts and effects a great economy of thought. He states (p. 26): ". . . physical theory never gives us the explanation of experimental laws; it never reveals realities hiding under the sensible appearances; but the more complete it becomes, the more we apprehend that the logical order in which theory orders experimental laws is the reflection of an ontological order, the more we suspect that the relations it established among the data of observation correspond to real relations among things, and the more we feel that theory tends to be a natural classification." (P. 30): "This characteristic of natural classification is marked, above all, by the fruitfulness of the theory which anticipates experimental laws not yet observed, and promotes their discovery." "That sufficiently justifies the search for physical theories, which cannot be called a vain and idle task even though it does not pursue the explanation of phenomena." How modern the "operational" view of a theory as a coded description of apperceptible facts! And, yet, how "dated" the need for a "metaphysical" justification of the theory as an approximation to the ontological order of hidden realities! The third chapter brings a lucid and highly interesting historical study of the development of physical theories. The author's thesis is that (p. 32) "When we analyze a theory created by a physicist who proposes to explain sensible appearances, we generally do not take long to recognize that this theory is formed of two really distinct parts: one is the simply representative part which proposes to classify (experimental) laws; the other is the explanatory part which proposes to take hold of the reality underlying the phenomena." "Everything good in the theory . . . is found in the representative

part. On the other hand, whatever is false in theory . . . is found above all in the explanatory part; the physicist has brought error into it, led by his desire to take hold of realities." The fourth chapter is devoted to a discussion of different types of creative minds as manifested in the "abstract" and the "model" types of physical theories. The author argues in favor of the former and criticizes severely the propensity of the English school of physicists, in particular, for devising "mechanical models" of each and every physical phenomenon. He warns (p. 93): ". . . we shall declare to the utilitarians, who think that they are making practical men by teaching only concrete things, that their pupils will sooner or later become routine manipulators, mechanically applying formulas they do not understand; for only abstract and general principles can guide the mind in unknown regions and suggest to it the solutions of unforeseen difficulties." And he pleads that the use of mechanical models, whose heuristic value he admits, should not suppress the search for an abstract and logically ordered theory. Now, half a century later, we can see the intrinsic truth of the author's views: the present status of the physical theory could not have been attained without the creation of abstract logical systems. "Utilitarians," oblivious of the author's warning, find themselves precisely in the predicament which he foresaw.

Part II deals with the structure of physical theory. The author's views have a peculiarly modern ring here. "Theoretical physics is mathematical physics." Both "quantities" and "qualities" (in the Aristotelian sense) are measurable and can be expressed by numbers. The aim of the theory is to keep the number of "irreducible" qualities to a minimum. Hence (p. 128) "a quality is never primary, except provisionally." (P. 133): ". . . at both its starting and terminal points, the mathematical development of a physical theory cannot be wedded to observable facts except by a translation" (by the intermediary of measurements). "But translation is treacherous . . ." ". . . in a *theoretical* fact there is nothing vague or indecisive." (P. 134): "A *practical* fact is not translated . . . by a single theoretical fact, but by a kind of bundle including an infinity of different theoretical facts." (P. 137): "A mathematical deduction . . . may . . . be useful or otiose, according to whether or not it permits us to derive a *practically definite* prediction of the result of an experiment whose conditions are *practically given*." (P. 143): " . . . This 'mathematics of approximation' is not a simpler and cruder form of mathematics. On the contrary, it is a more thorough and refined form . . ., requiring the solution of problems . . . transcending the methods at the disposal of algebra today." (1906!)

(Page 144): "An experiment in physics is not simply the observation of a phenomenon; it is, besides, the theoretical interpretation of this phenomenon." A truism yet to be learned by utilitarians! (P. 153): "Between the phenomena really observed in the course of an experiment and the result formulated by the physicist, there is interpolated a very complex intellectual elaboration which substitutes for the recital of concrete facts an abstract and symbolic judgment." "The theoretical interpretation of phenomena alone makes possible the use of instruments." (P. 155): "Thus, when a physicist does an experiment, two very distinct representations of the instrument . . . fill his mind: one is the image of the concrete instrument . . ., the other is a schematic model of the same instrument . . ., and it is on this ideal and symbolic instrument that he does his reasoning. . . ." (P. 165): "The laws of physics are symbolic relations." (P. 168): "A law of physics is, properly speaking, neither true nor false, but (is) approximate." Nowadays, we would use the term "probabilistic," instead. (P. 178): "The laws of physics can acquire this minuteness of detail only by sacrificing something of the fixed and absolute certainty of common-sense laws. There is a sort of balance between precision and uncertainty: one cannot be increased except to the detriment of the other." This "sort of balance" anticipated Heisenberg's formulation of the Uncertainty Principle by more than twenty years!

(Page 180): "The sole purpose of the physical theory is to provide a representation and classification of experimental laws; the only test permitting us to judge a physical theory and pronounce it good or bad is the comparison between the consequences of this theory and the experimental laws it has to represent and classify." (Page 188): "A

'crucial experiment' is impossible in physics." (P. 200): "The only experimental check on a physical theory which is not illogical consists in comparing the *entire system of the physical theory with the whole group of experimental laws. . . .*"

(Page 206): "In the course of its development, *a physical theory is free to choose any path it pleases, provided that it avoids any logical contradiction; in particular, it is free not to take account of experimental facts. This is no longer the case when the theory has reached its complete development.*" "We analyzed . . . the error of those who accept as principles only 'inductions consisting exclusively in erecting into general laws not the interpretation but *the very result of a very large number of* experiments.'" (P. 207): "There is another error . . .; it consists of requiring that all the operations performed by the mathematician connecting postulates with conclusions should have *a physical meaning* in wishing 'to reason only about *performable operations*' and in 'introducing only magnitudes accessible to experiment.'" Errors, alas, to which the utilitarian mind is particularly prone.

In the last chapter, the author considers with great insight the problem of the choice of hypotheses on which a physical theory is to be based. The logical requirements are: 1. no hypothesis should be self-contradictory; 2. hypotheses underlying a theory should not contradict one another; 3. the set of hypotheses *taken as a whole* should permit mathematical deduction of consequences representing with a sufficient degree of approximation the *totality* of experimental laws. (P. 220): "The physicist does not choose the hypotheses on which he will base a theory; they germinate in him without him." (P. 259): "Hypotheses cannot be deduced from axioms provided by common-sense knowledge."

The two articles "Physics of a Believer" (1905) and "The Value of Physical Theory" (1908) appearing in the appendix contain elaborations of some of the ideas of the principal work.

The present reviewer hopes that he has not unduly taxed the patience of the reader by quotations from this remarkable work. Many ideas expressed by the author, it is true, have become second nature to the "strong and narrow" (p. 57) abstract minds, to whom the present physical theory owes so much. But this work bears an important message, written in a remarkably lucid manner, to the "broad and weak" (p. 57) minds of the utilitarians whose tradition still pervades this country. This reviewer cannot advise too strongly every worker in pure and applied research to study this book with great care: he is bound to profit from the better insight gained into the intimate nature of the theories he uses and the experiments he makes. The intelligent general reader will profit from the author's admirable exposition of the historical development of the physical sciences and of the ethos of the true scientist.

The publishers of this English translation of the work of one of France's best minds have done a great service to this country. The translator has succeeded with admirable skill in preserving the fluency and lucidity of the original text. OTTO R. SPIES

ERRATUM: The title of the Homer E. Newell, Jr. book (Academic Press), reviewed in our March issue, p. 251, should be "High Altitude Rocket Research," instead of "High Altitude Research."

BOOK NOTES

MATERIALS AND PROCESSES, by James F. Young. Second edition, 1074 pages, illustrations, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $8.50.

Since the appearance of the first edition of this text in 1943, so much has happened in the field that this second edition has been enlarged by 50 per cent. Brought up-to-date in physical metallurgy and chemistry, in property data and process tolerances, and in the latest industry practices, this new version of *Materials and Processes* will be welcomed by engineers in all fields. The chapters are complete in themselves, including a short, up-to-date bibliography, making it easy for the reader to find a particular subject.

EXPERIMENTAL COLLEGE PHYSICS. A LABORATORY MANUAL, by Marsh W. White and Kenneth V. Manning. Third edition, 347 pages, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $5.00.

Basically a laboratory manual for experiments in general college physics, this new edition retains the good features of prior editions (1932 and 1940) and adds new material. Eight of the original experiments have been deleted and ten new ones added, while ten others have been incorporated into newly designed experiments. The approach—use of the scientific method through leading the student to use his reasoning powers—remains the same as in the previous editions.

A FIRST COURSE IN ORDINARY DIFFERENTIAL EQUATIONS, by Rudolph E. Langer. 249 pages, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $4.50.

This new introductory text in differential equations has been written by a gifted teacher at the University of Wisconsin. This teaching experience is evidenced in the clear, logical presentation of subject matter, complete with worked-out examples and applications. Designed primarily for science and engineering students, the text should find ready acceptance in these courses.

INTRODUCTION TO COLLEGE MATHEMATICS, by Carroll V. Newsom and Howard Eves. Second edition, 408 pages, 16 × 24 cm. New York, Prentice-Hall, Inc., 1954. Price, $5.75.

The second edition of this text will be welcomed in those classes in mathematics for the non-specialist. Designed as a single course, the text originally was published in 1946. The present revision incorporates minor changes suggested by students and teachers using the book, as well as a new chapter on the calculus. Professor Howard Eves, in coauthoring the revised work, brings to the task a rare knowledge of the history of mathematics, which is evident in the present work.

ELEMENTS OF ELECTRICAL ENGINEERING, by Arthur L. Cook and Clifford C. Carr. Sixth edition, 682 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $6.75.

The sixth edition of *Elements*—a text widely used for 30 years—needs little comment, except that the changes in this edition were made as a result of a nationwide survey to determine how the usefulness of the text could be increased. Nearly half the book has been rewritten, leaving the basic arrangement unchanged, while adding new material on electronics, new illustrations, and new problems. In its new format, the text should continue to serve as a clear and accurate introduction to electricity.

ELEMENTARY DIFFERENTIAL EQUATIONS, by Lyman M. Kells. Fourth edition, 266 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $4.00.

In this fourth edition of a standard work, the text changes represent the author's effort to clarify discussions in prior editions, with more emphasis on theory. In addition, nearly all lists of problems have been rewritten so that the easier problems are first. Also, new applications have been included. In its revised form, the text should continue to serve students wishing to learn the applications as well as the theory of differential equations.

CURRENT TOPICS

First Direct Conversion of Nuclear Energy to Usable Electricity. —A new method which, for the first time in history, makes it possible to convert atomic energy directly and simply into small but usable quantities of electrical energy sufficient to operate a transistor, has been announced by Brig. General David Sarnoff, Chairman of the Board of the Radio Corporation of America.

In his office at Radio City, General Sarnoff displayed an RCA Atomic Battery which operated the transistor to produce audible tones. This direct conversion of nuclear energy to electricity, he said, may prove to be as significant as Edison's conversion of electricity to light.

General Sarnoff said:

"For more than forty years, science has searched for a practical way of converting radiations from the atom's nucleus to electricity. Though our research is far from completed, successful operation of RCA's Atomic Battery in our laboratories represents a major breakthrough toward that goal."

The new type of battery consists of a radioactive source to which is coupled a wafer of semi-conducting crystal (germanium or silicon). An impurity material has been alloyed into the crystal to form a junction. The junction is similar electrically to those used in a junction transistor, but is considerably larger, with an area of 1/20th of a square inch.

Strontium-90, one of the most abundant of the materials resulting from the fission of uranium in a reactor, is a highly active source of beta particles—high speed electrons—and is one of the long-lived beta-emitting substances. Its half-life is roughly 20 years, i.e., every twenty years half of its radioactivity is dissipated.

In the battery, 1/300th of a cubic centimeter (a quantity that would fill a cube 1/16th of an inch on a side) of radioactive strontium is spread in a thin layer against the junction wafer. The layer of strontium bombards the semi-conducting crystal wafer with several billion electrons per second. As the electrons penetrate the wafer they release many more electrons, an average of 200,000 for each bombarding electron.

Previous radioactive generators simply captured the high-speed electrons as they came from the radioactive source with the result that they provided approximately one electron for each bombarding electron. In the present experimental atomic battery, each high-speed electron releases in the crystal, on the average, 200,000 low-speed electrons. These released electrons flow across the wafer's junction producing a voltage which can be applied to an electronic circuit and cause a current to flow. The electron action within the crystal wafer is known as the electron-voltaic effect, a phenomenon of solid-state physics which heretofore has not been put to any practical use.

When connected to the transistor oscillator circuit, the battery's 1/5 volt potential provides a current of 5 microamperes, an output of approximately one millionth of a watt. The best efficiency of energy conversion so far obtained exceeds 1%, i.e., the ratio of useful electrical power developed by the battery is at least 1/100th the energy

of the beta particles as they leave the radioactive source. The greater part of the original energy is lost as heat in the crystal wafer. As present techniques are refined, an efficiency of 10% appears to be a reasonable goal for such devices.

Greater power can be achieved by increasing the present 50 millicurie quantity of strontium-90 or by placing a number of such units in a single container.

Although in theory, virtually any radioactive material could be the source of an atomic battery, strontium-90 was chosen to activate the RCA device because of its high energy beta radiation, its relatively long life, its low shielding requirements and its availability in experimental quantities from the U. S. Atomic Energy Commission.

Strontium-90 is not now obtainable in completely purified form, that is, other fission products have not been entirely separated from it. Since some of the unwanted radioactive materials are emitters of gamma radiation, shielding is necessary in the laboratory device.

However, strontium-90 in purified form, emits only beta particles which, for the quantities that would be used in a small atomic battery, does not raise problems of shielding.

Strontium-90 costs about 50 cents for a thousandth of a curie today. A wide demand for the material in atomic batteries and other applications would warrant quantity processing of the material. This, it has been estimated, might bring its price down as low as two-tenths of a cent for a thousandth of a curie.

An aspect of Atomic Batteries that has yet to be determined accurately is the extent of the effect of the beta radiation on the crystal wafer. It is known that the crystal structure of many substances is gradually damaged by bombarding electrons. Further research is in progress to minimize these effects.

Superior Optical Cement.—A superior optical cement, plasticized cellulose caprate, has been developed by chemists at the Naval Research Laboratory. It is capable of withstanding the extreme temperature variations and other rigors of Naval service and appears suitable for replacement of Canada balsam in all types of optical instruments. This synthetic resin is an improvement over the unplasticized material, which has been standard in the Navy for over five years for airborne optical instruments, in that it is sufficiently fluid to be cemented at a temperature of less than 250 degrees F, permitting the cementing of large camera lenses.

Project "Tinkertoy" Drawings Available.—Drawings for hand tools required to set up pilot runs or for model shop production of electronic modules developed under "Project Tinkertoy" are now offered to U. S. Industry. The name "Project Tinkertoy," originally assigned to the project during its development stage has been dropped, and it will hereafter be referred to as "modular design of electronics," and "mechanized production of electronics." The process unveiled last September, makes possible the manufacture of certain electronic equipment through mechanized assembly of bulk or raw materials with minimum hand labor and at considerable savings in time. The drawings include those of jigs, dies and fixtures, and an engineering handbook of the hand tool process. They may be obtained through the Office of Technical Services, Department of Commerce, Washington 25, D. C. Also available is a summary of the entire project.

Plastic Screens Being Tested.—Plastic-coated glass fiber insect screens may be found to have large potential use in military construction if they withstand exhaustive natural weathering tests being conducted under rigorous climatic conditions by the Engineer Research and Development Laboratories, Fort Belvoir, Va.

According to Mr. James M. Osborn, project engineer of ERDL's Materials Branch, long-range tests are underway to determine their capabilities at five different sites which provide a wide variety of climatic conditions. They are being subjected to the desert at Yuma, Arizona; the Arctic at Fort Churchill, Canada; and the tropics in Panama. They are also fighting off occasional hurricanes in Florida, and enjoying comparatively smooth going at Fort Belvoir.

Numerous reports from Army posts scattered throughout the world concerning the inability of conventional screens to hold up prompted the Laboratories to investigate the feasibility of using the new plastic-coated type.

Some metal screens disintegrate within six months along sea coast areas because of excessive corrosion and leave disfiguring stains on window sills, door frames and sides of buildings.

Investigations proved that the new screens are resistant to corrosion. The plastic coating is only slightly charred when touched by a lighted cigarette.

Made of raw materials which are readily available, even in time of war, the use of the screens would conserve critical materials needed for more important items for the defense of our country.

USDA Cotton-Flameproofing Treatment.—A publication has been issued by the U. S. Department of Agriculture (AIC–364, November 2, 1953, processed) to set forth technical details on a new, durable, flameproof and glowproof, and to a lesser extent wrinkle- and rot-resistant finish for cotton textiles, developed by scientists of its Southern Utilization Research Branch, New Orleans.

The treatment arose from work done by W. A. Reeves and J. D. Guthrie, in research undertaken by the Southern Branch because of the great need for a better, durable-type, flame-retardant finish suitable for many of the end uses of cotton. This work was supported in part by the Quartermaster Corps.

Key discoveries are: Tetrakis-(hydroxymethyl) phosphonium chloride (THPC) reacts with a variety of amino compounds to form insoluble, flameproof resins; and permanent flame-resistance and other desirable properties are imparted to cotton fabrics by treating with an aqueous solution containing THPC with methylolmelamine and urea, followed by drying and curing.

Urea and melamine polymerize with THPC to form the resin *inside the fibers,* and this resin does not wash out. The degree of flameproofing imparted depends on the amount of resin formed and on the type of fabric construction. The treatment can be applied either continuously or in steps on standard chemical-finishing equipment. A typical solution contains 15.8 per cent THPC, 9.5 per cent trimethylolmelamine, 9.9 per cent urea, and 3.0 per cent triethanolamine.

THPC, $(HOCH_2)_4$ PCL, is a crystalline compound, soluble in water and in many organic solvents. Produced by saturating a water solution of formaldehyde and hydrochloric acid with phosphine, and then evaporating the solution, it is available from at least one chemical company in limited quantities.

The USDA publication describes application of the treatment to different

constructions of cloth, drying and curing conditions, and properties of the treated materials. A free copy may be obtained by writing the Southern Regional Research Laboratory, 2100 Robert E. Lee Boulevard, New Orleans 19, Louisiana.

"See-Thru" Drawer Cabinets.—General Industrial Co. of Chicago announces production of a complete line of "See-Thru" drawer cabinets for small-parts filing and storage in factories, offices and school shops, home workshops and garages. The popular Model J–20 consists of twenty crystal-clear lifetime guaranteed plastic spill-proof drawers, $5\frac{1}{8}$ in. long, $2\frac{3}{4}$ in. wide and $1\frac{7}{16}$ in. high, in a welded all-steel cabinet. Over-all size: $10\frac{1}{4}$ in. high, $12\frac{1}{2}$ in. wide and 6 in. deep. The cabinet has an attractive silver-gray hammer finish and is equipped with rubber feet. Adjustable drawer dividers and identification labels are included.

Other "See-Thru" drawer units now in production include models ranging from 8 to 128 drawers, models with larger size or metal drawers, and portable models with carrying handles. Over 750 combinations, to suit user's exact requirements, can be supplied.

New Magnetic Drum Differential Analyzer.—An electronic computer with a capacity sixty percent greater than any of its kind yet built has been placed in regular operation at Stevens Institute of Technology, Hoboken, N. J. Designed and constructed by the engineering college's Experimental Towing Tank Laboratory to solve problems involved in its research on naval and air craft, the computer is known as a magnetic drum digital differential analyzer. Because differential equations, the class of problem the machine has been designed to solve, are encountered in studying and predicting the characteristics of almost all objects that move, the new computer can be used in investigations on guided missiles, torpedoes, rockets, jet engines, submarines, gas turbines and industrial machinery, as well as surface craft and airplanes.

The computer, known as the ETT-100, has 100 integrators or problem-solving centers as against 60 for the next largest one of its kind. This capacity can be doubled to 200 integrators at any time, according to designer Stanton M. Shackell, chief of instrumentation at the Towing Tank. Increasing capacity simply would mean adding a larger magnetic drum and tying it in with the present electronic system, he said. This is made possible, he explained, by the unusual method of construction employed which features standardized plug-in electronic units hung on open-work frames.

These self-contained units are readily detachable and, because they are exposed, any that break down in service can be spotted easily and replaced with a minimum of difficulty. The open framework, in addition to permitting easy accessibility to component parts, also makes it easier to keep them ventilated. The Stevens computer, like other electronic types, generates its own heat because of the batteries of vacuum tubes it employs. The problem of disposing of the heat has interfered with the operation of other computers, most of which are enclosed in cabinets.

One feature which makes the new computer unique among differential analyzers, Mr. Shackell said, is its ability to make decisions based on its own computations. For example, in considering problems connected with the flight of a guided missile, the machine can decide what rules of flight to apply as the speed of the missile varies between subsonic and supersonic levels.

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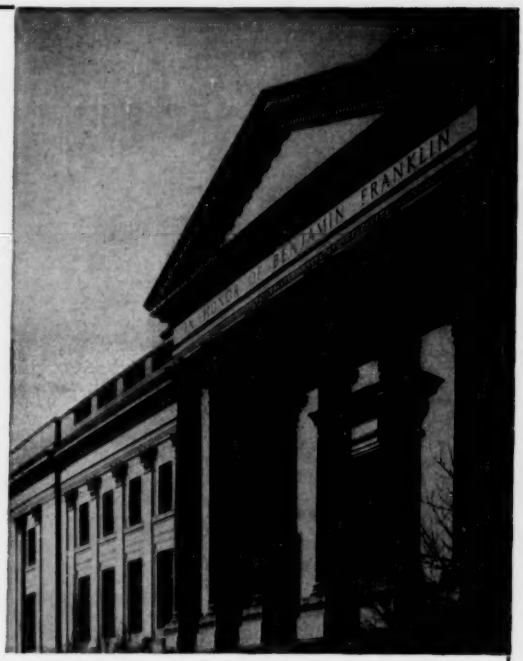

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